Compl



TREASURY DEPARTMENT.



UNITED STATES

# COAST AND GEODETIC SURVEY.

HENRY S. PRITCHETT,
SUPERINTENDENT.

## BULLETINS.

VOL. II.

26-35

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1899.

# BULLETINS.

### Vol. II—Nos. 26 to 35.

Bulletins are issued by the Survey from time to time as material for them accumulates. They are intended to give early announcement of work accomplished or information of importance obtained, and will, in many cases, anticipate the usual means of publication afforded by the Annual Reports.

Those already published, Nos. 1 to 25, inclusive, in quarto form, constitute Vol. I; Nos. 26 to 35, inclusive, in octavo, constitute Vol. II. Vol. III begins with No. 36.

UNITED STATES
COAST AND GEODETIC SURVEY.

T. C. MENDENHALL,
SUPERINTENDENT.

BULLETIN NO. 26.

# FUNDAMENTAL STANDARDS
OF
# LENGTH AND MASS.

APPROVED FOR PUBLICATION APRIL 5, 1893.

Bulletins are issued by the Survey from time to time as material for them accumulates. They are intended to give early announcement of work accomplished or information of importance obtained, and will in many cases anticipate the usual means of publication afforded by the Annual Reports. Those already published, Nos. 1 to 25 inclusive, in quarto form, have their pages numbered consecutively and constitute Vol. I. With the present number Vol. II begins; it will be published in octavo.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1893.

2—1567

# FUNDAMENTAL STANDARDS
OF
# LENGTH AND MASS.

While the Constitution of the United States authorizes Congress to "fix the standard of weights and measures," this power has never been definitely exercised, and but little legislation has been enacted upon the subject. Washington regarded the matter of sufficient importance to justify a special reference to it in his first annual message to Congress (January, 1790), and Jefferson, while Secretary of State, prepared a report at the request of the House of Representatives, in which he proposed (July, 1790) "to reduce every branch to the decimal ratio already established for coins, and thus bring the calculation of the principal affairs of life within the arithmetic of every man who can multiply and divide." The consideration of the subject being again urged by Washington, a committee of Congress reported in favor of Jefferson's plan, but no legislation followed. In the meantime the executive branch of the Government found it necessary to procure standards for use in the collection of revenue and other operations in which weights and measures were required, and the Troughton 82-inch brass scale was obtained for the Coast and Geodetic Survey in 1814, a platinum kilogramme and metre, by Gallatin, in 1821, and a Troy pound from London in 1827, also by Gallatin. In 1828 the latter was, by act of Congress, made the standard of mass for the Mint of the United States, and although totally unfit for such purpose, it has since remained the standard for coinage purposes.

In 1830 the Secretary of the Treasury was directed to cause a comparison to be made of the standards of weight and measure used at the principal Custom-houses, as a result of which, large discrepancies were disclosed in the weights and measures in use. The Treasury Department being obliged to execute the constitutional provision that all duties, imposts, and excises shall be uniform throughout the United States, adopted the Troughton scale as the standard of length; the avoirdupois pound to be derived from the Troy pound of the Mint, as the unit of mass. At the same time the Department adopted the wine gallon of 231 cubic inches for liquid measure and the Winchester bushel of 2150·42 cubic inches for dry measure. In 1836 the Secretary of the Treasury was authorized to cause a complete set of all weights and measures adopted as standards by the Department for the use of Custom-houses and for other purposes, to be delivered to the Governor of each State in the Union for the use of the States respectively, the object being to encourage uniformity of weights and measures throughout the Union. At this time, several States had adopted standards differing from those used in the Treasury Department, but after a time these were rejected,

and finally nearly all the States formally adopted by act of legislature the standards which had been put in their hands by the National Government. Thus a good degree of uniformity was secured, although Congress had not adopted a standard of mass or of length, other than for coinage purposes as already described.

The next, and in many respects the most important legislation upon the subject was the act of July 28, 1866, making the use of the metric system lawful throughout the United States, and defining the weights and measures in common use in terms of the units of this system. This was the first *general* legislation upon the subject, and the metric system was thus the first, and thus far the only system made generally legal throughout the country.

In 1875 an International Metric Convention was agreed upon by seventeen governments, including the United States, at which it was undertaken to establish and maintain at common expense a permanent International Bureau of Weights and Measures, the first object of which should be the preparation of a new international standard metre and a new international standard kilogramme, copies of which should be made for distribution among the contributing governments. Since the organization of the Bureau, the United States has regularly contributed to its support, and in 1889 the copies of the new international prototypes were ready for distribution. This was effected by lot, and the United States received metres Nos. 21 and 27, and kilogrammes Nos. 4 and 20. The metres and kilogrammes are made from the same material, which is an alloy of platinum with ten per cent of iridium.

On January 2, 1890, the seals which had been placed on metre No. 27, and kilogramme No. 20, at the International Bureau of Weights and Measures near Paris, were broken in the Cabinet room of the Executive Mansion, by the President of the United States, in the presence of the Secretary of State and the Secretary of the Treasury, together with a number of invited guests. They were thus adopted as the National Prototype Metre and Kilogramme.

The Troughton scale, which in the early part of the century had been tentatively adopted as a standard of length, has long been recognized as quite unsuitable for such use, owing to its faulty construction and the inferiority of its graduation. For many years, in standardizing length measures, recourse to copies of the imperial yard of Great Britain had been necessary, and to the copies of the metre of the archives in the Office of Weights and Measures. The standard of mass originally selected was likewise unfit for use for similar reasons, and had been practically ignored.

The recent receipt of the very accurate copies of the International Metric Standards, which are constructed in accord with the most advanced conceptions of modern metrology, enables comparisons to be made directly with those standards, as the equations of the

National Prototypes are accurately known. It has seemed, therefore, that greater stability in weights and measures, as well as much higher accuracy in their comparison, can be secured by accepting the International Prototypes as the fundamental standards of length and mass. It was doubtless the intention of Congress that this should be done when the International Metric Convention was entered into in 1875; otherwise there would be nothing gained from the annual contributions to its support which the Government has constantly made. Such action will also have the great advantage of putting us in direct relation in our weights and measures, with all civilized nations, most of which have adopted the metric system for exclusive use. The practical effect upon our customary weights and measures is, of course, nothing. The most careful study of the relation of the yard and the metre has failed thus far to show that the relation as defined by Congress in the Act of 1866, is in error. The pound as there defined, in its relation to the kilogramme, differs from the imperial pound of Great Britain by not more than one part in one hundred thousand, an error, if it be so called, which utterly vanishes in comparison with the allowances in all ordinary transactions. Only the most refined scientific research will demand a closer approximation, and in scientific work the kilogramme itself is now universally used, both in this country and in England.*

In view of these facts, and the absence of any material normal standards of customary weights and measures, the Office of Weights and Measures, with the approval of the Secretary of the Treasury, will in the future, regard the International Prototype Metre and Kilogramme as fundamental standards, and the customary units, the yard and the pound, will be derived therefrom in accordance with the Act of July 28, 1866. Indeed, this course has been practically forced upon this Office for several years, but it is considered desirable to make this formal announcement for the information of all interested in the science of metrology or in measurements of precision.

T. C. MENDENHALL,
*Superintendent of Standard Weights and Measures.*

Approved:
J. G. CARLISLE,
*Secretary of the Treasury.*
April 5, 1893.

*NOTE.—Reference to the Act of 1866, results in the establishment of the following:

*Equations.*

$$1 \text{ yard} = \frac{3600}{3937} \text{ metre.}$$

$$1 \text{ pound avoirdupois} = \frac{1}{2{\cdot}2046} \text{ kilo.}$$

A more precise value of the English pound avoirdupois is $\frac{1}{2{\cdot}20462}$ kilo., differing from the above by about one part in one hundred thousand, but the equation established by law is sufficiently accurate for all ordinary conversions.

As already stated, in work of high precision the kilogramme is now all but universally used and no conversion is required.

UNITED STATES
COAST AND GEODETIC SURVEY.

T. C. MENDENHALL,
SUPERINTENDENT.

---

**BULLETIN No. 27.**

---

# RESULTS OF OBSERVATIONS

FOR THE

# VARIATIONS OF LATITUDE

## AT WAIKIKI, HAWAIIAN ISLANDS,

IN COÖPERATION WITH THE WORK OF THE

## INTERNATIONAL GEODETIC ASSOCIATION.

---

A report by E. D. PRESTON, ASSISTANT.

Submitted for publication May 16, 1893.

---

Bulletins are issued by the Survey from time to time as material for them accumulates. They are intended to give early announcement of work accomplished or information of importance obtained, and will in many cases anticipate the usual means of publication afforded by the Annual Reports. Those already published Nos. 1 to 25 inclusive, in quarto form, have their pages numbered consecutively and constitute Vol. I. No. 26 begins Vol. II, which will be published in octavo.

---

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1893.

2—1642

# RESULTS OF OBSERVATIONS FOR THE VARIATIONS OF LATITUDE AT WAIKIKI, NEAR HONOLULU, HAWAIIAN ISLANDS, IN COÖPERATION WITH THE WORK OF THE INTERNATIONAL GEODETIC ASSOCIATION.

E. D. PRESTON, Assistant.

During the latter half of 1891 and the first half of 1892 an extensive series of astronomical observations was made at Waikiki, near Honolulu, in the Hawaiian Islands. The object of this work was to study the changes of latitude. The party was a joint one, and was composed of representatives of the International Geodetic Association and the United States Coast and Geodetic Survey. Simultaneously, and following practically the same program, observations were made at Berlin, at Washington, and at San Francisco.

The results of the work done at Berlin and Washington, and of that executed at Waikiki on the part of the International Association, have already appeared. The present paper has to deal with those made on the part of our own Service at the last-named place. The data here given are taken from the manuscript report on this work, which will appear in detail as one of the appendices to the report of the Superintendent of the Coast and Geodetic Survey for the year 1892.

The instrument used was a zenith telescope of 112·1 centimetres focal length, with a clear aperture of 8·2 centimetres. A magnifying power of 100 was used. Two levels were read and three bisections were made on each star.

The geodetic position of the observatory referred to the Hawaiian Government Survey is—

| | | | | |
|---|---|---|---|---|
| Latitude | 21° | 16′ | 26·7″ | North. |
| Longitude | 157 | 50 | 1·2 | West of Gr. |

The following is a list of the stars observed, with their mean places for 1892·0, together with the proper motion ($\mu$) and the square of the probable error ($e^2$) for the declinations:

## GROUP I.

| Pair. | No. Pulkowa. | Right ascension, 1892·0. | | | Declination, 1892·0. | | | $e^2$. | $\mu$. |
|---|---|---|---|---|---|---|---|---|---|
| | | h. | m. | s. | ° | ′ | ″ | | ″ |
| 1 | 2021 | 13 | 27 | 46 | − 7 | 4 | 3·21 | 0·07 | + 0·021 |
| | 2027 | | 30 | 2 | + 49 | 34 | 5·82 | ·02 | + ·021 |
| 2 | 2056 | | 41 | 42 | 26 | 14 | 38·75 | ·03 | − ·077 |
| | 2064 | | 44 | 16 | 16 | 20 | 1·53 | ·02 | + ·029 |
| 3 | 2093 | 14 | 3 | 37 | 44 | 22 | 5·68 | ·03 | − ·032 |
| | 2113 | | 13 | 59 | − 1 | 45 | 57·56 | ·05 | − ·079 |
| 4 | 2126 | | 21 | 26 | + 19 | 42 | 45·63 | ·03 | + ·017 |
| | 2134 | | 27 | 40 | 22 | 44 | 8·58 | ·04 | + ·030 |
| 5 | 2139 | | 29 | 59 | 30 | 12 | 51·90 | ·03 | + ·119 |
| | 2146 | | 36 | 32 | 12 | 7 | 34·79 | ·02 | − ·105 |
| 6 | 2163 | | 46 | 14 | 37 | 42 | 55·02 | ·04 | + ·090 |
| | 2177 | | 54 | 0 | 4 | 59 | 56·95 | ·05 | − ·023 |
| 7 | 2204 | 15 | 9 | 58 | 29 | 33 | 55·05 | ·04 | + ·019 |
| | 2214 | | 17 | 16 | 12 | 57 | 15·47 | ·04 | − ·032 |

## GROUP II.

| Pair. | No. Pulkowa. | Right ascension, 1892·0. | | | Declination, 1892·0. | | | $e^2$. | $\mu$. |
|---|---|---|---|---|---|---|---|---|---|
| | | h. | m. | s. | ° | ′ | ″ | | ″ |
| 1 | 2387 | 16 | 37 | 14 | 27 | 7 | 30·74 | 0·07 | − 0·062 |
| | 2409 | | 47 | 10 | 15 | 9 | 20·51 | ·04 | − ·014 |
| 2 | 2420 | | 56 | 24 | 22 | 47 | 29·61 | ·05 | − ·043 |
| | 2430 | | 59 | 59 | 19 | 44 | 54·97 | ·04 | − ·016 |
| 3 | 2437 | 17 | 4 | 6 | 24 | 37 | 38·76 | ·08 | − ·060 |
| | 2456 | | 15 | 33 | 18 | 10 | 7·51 | ·06 | − ·037 |
| 4 | 2464 | | 19 | 41 | 16 | 24 | 2·32 | ·05 | − ·044 |
| | 2479 | | 26 | 22 | 26 | 11 | 32·19 | ·03 | + ·010 |
| 5 | 2501 | | 38 | 3 | 24 | 39 | 7·43 | ·03 | − ·118 |
| | 2509 | | 42 | 22 | 17 | 44 | 14·00 | ·04 | − ·017 |
| 6 | 2513 | | 44 | 26 | 25 | 39 | 32·49 | ·03 | − ·049 |
| | 2532 | | 55 | 15 | 16 | 45 | 26·80 | ·09 | − ·004 |
| 7 | 2571 | 18 | 13 | 5 | 13 | 44 | 11·14 | 1·0 | − ·02 |
| | 2580 | | 16 | 13 | 28 | 56 | 8·76 | ·14 | + ·001 |
| 8 | 2595 | | 22 | 20 | 26 | 23 | 5·89 | ·04 | − ·027 |
| | 2621 | | 32 | 18 | 16 | 6 | 21·20 | ·04 | + ·040 |

## GROUP III.

| Pair. | No. Pulkowa. | Right ascension, 1892·0. | | | Declination, 1892·0. | | | $e^2$. | $\mu$. |
|---|---|---|---|---|---|---|---|---|---|
| | | h. | m. | s. | ° | ′ | ″ | | ″ |
| 1 | 2633 | 18 | 40 | 10 | 23 | 28 | 54·41 | 0·06 | − 0·085 |
| | 2647 | | 44 | 11 | 19 | 12 | 28·93 | ·06 | − ·02 |
| 2 | 2681 | | 55 | 21 | 26 | 3 | 52·78 | ·06 | − ·017 |
| | 2703 | 19 | 3 | 7 | 16 | 41 | 33·76 | ·05 | − ·319 |
| 3 | 2718 | | 7 | 37 | 31 | 6 | 12·17 | ·03 | − ·009 |
| | 2743 | | 14 | 48 | 11 | 20 | 6·62 | ·18 | + ·029 |
| 4 | 2798 | | 33 | 52 | 5 | 9 | 6·99 | ·03 | − ·009 |
| | 2822 | | 40 | 23 | 37 | 5 | 37·24 | ·02 | + ·038 |
| 5 | 2824 | | 42 | 27 | 32 | 37 | 25·31 | ·20 | − ·01 |
| | 2832 | | 45 | 51 | 10 | 8 | 43·83 | ·05 | − ·163 |
| 6 | 2862 | | 54 | 33 | 22 | 48 | 27·34 | ·02 | + ·007 |
| | 2886 | 20 | 0 | 22 | 19 | 40 | 54·32 | ·05 | + ·081 |
| 7 | 2893 | | 2 | 39 | 9 | 5 | 10·33 | ·06 | + ·005 |
| | 2925 | | 11 | 12 | 33 | 24 | 8·09 | ·08 | − ·102 |
| 8 | 2936 | | 13 | 48 | 37 | 41 | 49·86 | ·06 | − ·010 |
| | 2949 | | 17 | 50 | 4 | 59 | 53·39 | ·05 | − ·036 |

## GROUP IV.

| Pair. | No. Pulkowa. | Right ascension, 1892·0. | | | Declination, 1892·0. | | | $e^2$. | $\mu$. |
|---|---|---|---|---|---|---|---|---|---|
| | | h. | m. | s. | ° | ′ | ″ | | ″ |
| 1 | 3155 | 21 | 34 | 5 | 1 | 45 | 29·83 | 0·09 | − 0·083 |
| | 3170 | | 38 | 46 | 40 | 39 | 41·17 | ·07 | ·000 |
| 2 | 3182 | | 41 | 45 | 2 | 11 | 11·62 | ·08 | − ·022 |
| | 3192 | | 45 | 17 | 40 | 38 | 43·24 | ·07 | ·000 |
| 3 | *2899 | 22 | 2 | 0 | 24 | 49 | 3·28 | ·02 | + ·006 |
| | 3256 | | 8 | 0 | 17 | 44 | 46·56 | ·9 | − ·075 |
| 4 | 3274 | | 11 | 16 | 37 | 12 | 39·17 | ·04 | − ·005 |
| | 3279 | | 15 | 1 | 5 | 14 | 48·37 | ·04 | − ·018 |
| 5 | 3315 | | 30 | 37 | 19 | 43 | 7·78 | ·09 | − ·101 |
| | *3010 | | 41 | 20 | 22 | 59 | 50·50 | ·02 | − ·016 |
| 6 | 3345 | | 47 | 10 | 42 | 44 | 17·70 | ·03 | + ·009 |
| | 3367 | | 55 | 6 | − 0 | 23 | 38·49 | ·03 | + ·008 |
| 7 | 3390 | 23 | 3 | 9 | + 1 | 32 | 23·89 | ·05 | + ·108 |
| | 3419 | | 13 | 16 | 41 | 11 | 1·85 | ·04 | − ·004 |
| 8 | 3436 | | 17 | 38 | 11 | 43 | 18·36 | ·03 | − ·032 |
| | 3463 | | 28 | 36 | 30 | 43 | 44·90 | ·02 | − ·019 |

* Bradley.

## GROUP V.

| Pair. | No. Pulkowa. | Right ascension, 1892·0. | | | Declination, 1892·0. | | | $e^2$. | $\mu$. |
|---|---|---|---|---|---|---|---|---|---|
| | | h. | m. | s. | ° | ′ | ″ | | ″ |
| 1 | 88 | 0 | 40 | 12 | 44 | 16 | 15·13 | 0·06 | −0·014 |
| | 111 | | 47 | 29 | −1 | 43 | 51·11 | ·03 | − ·020 |
| 2 | 122 | | 51 | 59 | 28 | 24 | 29·44 | ·03 | − ·025 |
| | 138 | | 59 | 23 | 14 | 21 | 53·99 | ·05 | + ·033 |
| 3 | 170 | 1 | 7 | 53 | 24 | 0 | 42·00 | ·05 | − ·030 |
| | 199 | | 20 | 26 | 18 | 36 | 36·52 | ·04 | + ·017 |
| 4 | 211 | | 24 | 31 | 5 | 35 | 13·03 | ·03 | − ·044 |
| | 216 | | 28 | 2 | 36 | 40 | 59·73 | ·03 | − ·016 |
| 5 | 235 | | 34 | 12 | 40 | 1 | 47·52 | ·03 | − ·026 |
| | *251 | | 47 | 58 | 2 | 39 | 14·74 | ·03 | + ·008 |
| 6 | 270 | | 51 | 27 | 17 | 17 | 23·94 | ·04 | − ·032 |
| | 296 | 2 | 0 | 42 | 25 | 11 | 20·46 | ·06 | − ·031 |
| 7 | 331 | | 12 | 7 | 19 | 24 | 4·56 | ·03 | − ·002 |
| | 358 | | 23 | 4 | 22 | 59 | 11·79 | ·06 | − ·018 |
| 8 | 367 | | 27 | 34 | 18 | 24 | 12·55 | ·12 | + ·005 |
| | 375 | | 30 | 47 | 24 | 10 | 36·09 | ·02 | − ·019 |

* Bradley.

## GROUP VI.

| Pair. | No. Pulkowa. | Right ascension, 1892·0. | | | Declination, 1892·0. | | | $e^2$. | $\mu$. |
|---|---|---|---|---|---|---|---|---|---|
| | | h. | m. | s. | ° | ′ | ″ | | ″ |
| 1 | 598 | 4 | 1 | 7 | 37 | 26 | 36·80 | 0·07 | −0·180 |
| | 606 | | 5 | 35 | 5 | 14 | 29·71 | ·07 | + ·010 |
| 2 | 629 | | 13 | 4 | 20 | 52 | 49·46 | ·06 | − ·050 |
| | 662 | | 21 | 36 | 21 | 22 | 42·17 | ·06 | − ·066 |
| 3 | 686 | | 28 | 24 | 5 | 20 | 29·01 | ·05 | − ·062 |
| | 725 | | 42 | 38 | 37 | 17 | 48·94 | ·03 | + ·033 |
| 4 | 732 | | 45 | 3 | 18 | 39 | 19·68 | ·04 | − ·046 |
| | 751 | | 51 | 15 | 23 | 46 | 45·41 | ·10 | − ·033 |
| 5 | 796 | 5 | 7 | 39 | 2 | 43 | 55·50 | ·09 | − ·013 |
| | 810 | | 11 | 33 | 40 | 0 | 8·44 | ·04 | − ·667 |
| 6 | 824 | | 15 | 51 | 8 | 19 | 15·77 | ·07 | + ·005 |
| | 841 | | 19 | 40 | 34 | 17 | 45·71 | ·07 | − ·015 |
| 7 | 866 | | 25 | 53 | 18 | 30 | 47·88 | ·04 | − ·014 |
| | 874 | | 28 | 51 | 23 | 58 | 1·37 | ·04 | − ·031 |
| 8 | 939 | | 47 | 59 | 20 | 15 | 19·68 | ·03 | − ·108 |
| | 960 | | 55 | 10 | 22 | 23 | 50·48 | ·04 | − ·024 |

## GROUP VII.

| Pair. | No. Pulkowa. | Right ascension, 1892·0. | | | Declination, 1892·0. | | | $e^2$. | $\mu$. |
|---|---|---|---|---|---|---|---|---|---|
| | | h. | m. | s. | ° | ′ | ″ | | ″ |
| 1 | 1164 | 7 | 4 | 41 | 27 | 2 | 0·15 | 0.04 | −0·058 |
| | 1173 | | 6 | 39 | 15 | 21 | 32·51 | ·15 | + ·015 |
| 2 | 1198 | | 16 | 53 | 25 | 15 | 26·93 | ·03 | − ·029 |
| | 1217 | | 25 | 35 | 17 | 18 | 54·88 | ·07 | − ·088 |
| 3 | 1223 | | 28 | 41 | 46 | 25 | 3·51 | ·07 | − ·040 |
| | 1232 | | 31 | 55 | − 3 | 52 | 13·01 | ·04 | + ·020 |
| 4 | 1250 | | 40 | 33 | 33 | 40 | 48·22 | ·02 | − ·042 |
| | *529 | | 51 | 24 | 8 | 55 | 46·55 | ·25 | − ·025 |
| 5 | 1291 | | 55 | 44 | − 1 | 5 | 35·72 | ·06 | − ·078 |
| | 1298 | | 59 | 41 | 43 | 34 | 10·39 | ·07 | − ·056 |
| 6 | 1345 | 8 | 21 | 3 | − 3 | 37 | 56·96 | ·04 | − ·045 |
| | 1376 | | 33 | 53 | 46 | 12 | 44·13 | ·04 | + ·083 |
| 7 | 1410 | | 45 | 54 | 32 | 52 | 42·29 | ·05 | + ·014 |
| | 1429 | | 51 | 53 | 9 | 48 | 12·15 | ·07 | — ·000 |
| 8 | 1453 | 9 | 2 | 26 | 27 | 4 | 32·24 | ·04 | − ·384 |
| | 1464 | | 6 | 23 | 15 | 25 | 50·97 | ·05 | + ·236 |

* Greenwich, 87.

## GROUP VIII.

| Pair. | No. Pulkowa. | Right ascension, 1892·0. | | | Declination, 1892·0. | | | $e^2$. | $\mu$. |
|---|---|---|---|---|---|---|---|---|---|
| | | h. | m. | s. | ° | ′ | ″ | | ″ |
| 1 | 1585 | 10 | 2 | 10 | 10 | 31 | 36·16 | 0·03 | −0·062 |
| | 1598 | | 8 | 54 | 32 | 00 | 14·13 | ·03 | − ·003 |
| 2 | 1624 | | 19 | 34 | 9 | 20 | 1·16 | ·04 | − ·035 |
| | 1640 | | 25 | 43 | 32 | 56 | 1·22 | ·03 | + ·011 |
| 3 | 1656 | | 32 | 58 | 38 | 28 | 22·62 | ·05 | − ·030 |
| | 1667 | | 37 | 3 | 4 | 8 | 49·99 | ·04 | + ·020 |
| 4 | 1713 | | 54 | 48 | 39 | 47 | 31·41 | ·05 | − ·022 |
| | 1727 | 11 | 1 | 24 | 2 | 32 | 30·35 | ·03 | − ·072 |
| 5 | 1743 | | 13 | 15 | 38 | 46 | 40·06 | ·06 | − ·080 |
| | 1754 | | 20 | 6 | 3 | 53 | 45·71 | ·09 | − ·043 |
| 6 | *4875 | | 22 | 23 | − 1 | 6 | 20·37 | ·11 | − ·002 |
| | 1763 | | 24 | 40 | 43 | 45 | 57·42 | ·04 | + ·063 |
| 7 | 1789 | | 40 | 18 | 7 | 8 | 4·47 | ·04 | − ·179 |
| | 1795 | | 44 | 5 | 35 | 31 | 54·18 | ·11 | − ·010 |
| 8 | 1802 | | 50 | 7 | 16 | 14 | 51·97 | ·04 | + ·005 |
| | 1827 | | 6 | 22 | 26 | 28 | 18·52 | ·05 | − ·050 |

* Yarnall.

The stars were selected by Dr. Marcuse, Astronomer representing the International Geodetic Association, and consist of sixty-three pairs, comprising eight groups. Each group was continuously observed for three months. In the reduction Professor Albrecht's method has been used: "Provisorische Resultate der Beobachtungsreihen in Berlin, Potsdam und Prag betreffend die veränderlichkeit der Polhöhe." Berlin, 1890.

The mean places of the stars were deduced by Mr. Farquhar, and they depend, as far as the proper motions are concerned, on the systematic corrections of Boss to the declinations of the Bradley-Auwers Catalogue. Some idea of the accuracy of these places may be gained from the following table, which gives the reduction of each pair to the mean declination system of its own group:

REDUCTION TO MEAN DECLINATION SYSTEM.

| Group. | Pairs. | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| | " | " | " | " | " | " | " | " |
| I | − 0·10 | + 0·20 | + 0·05 | − 0·04 | − 0·48 | + 0·05 | + 0·33 | ........ |
| II | − ·12 | + ·31 | − ·42 | + ·42 | + ·08 | − ·59 | − ·22 | + 0·43 |
| III | − ·34 | + ·05 | − ·16 | − ·18 | + ·46 | − ·10 | + ·40 | − ·12 |
| IV | − ·38 | + ·40 | + ·87 | − ·11 | − ·69 | + ·22 | − ·55 | + ·24 |
| V | + ·14 | + ·15 | − ·76 | + ·04 | + ·16 | + ·37 | − ·20 | + ·11 |
| VI | − ·70 | + ·30 | + ·27 | + ·27 | + ·21 | − ·34 | + ·19 | − ·20 |
| VII | − ·41 | − ·05 | − ·07 | + ·17 | + ·73 | − ·49 | − ·01 | + ·11 |
| VIII | + ·11 | + ·13 | − ·47 | − ·07 | − ·07 | + ·28 | + ·01 | + ·08 |

After each pair was reduced to the mean declination system, the daily means were taken for each group. In order to compare the groups, mean values were taken for those periods during which the groups overlapped, and we thus have the following values for the latitude. (The tens place in all the computations was omitted to save labor. The latitude is 21° 16′ 24″ +):

| I | II | III | IV | V | VI | VII | VIII | I | II |
|---|---|---|---|---|---|---|---|---|---|
| ″<br>4·50 | ″<br>4·45 | | | | | | | | |
| | 4·13 | ″<br>4·17 | | | | | | | |
| | | 4·13 | ″<br>3·88 | | | | | | |
| | | | 3·87 | ″<br>4·02 | | | | | |
| | | | | 4·13 | ″<br>4·09 | | | | |
| | | | | 4·24 | | ″<br>4·22 | | | |
| | | | | | 4·21 | 4·38 | | | |
| | | | | | 4·25 | | ″<br>4·47 | | |
| | | | | | | 4·63 | 4·68 | | |
| | | | | | | | 4·71 | ″<br>4·65 | |
| | | | | | | | 4·74 | | ′<br>4·87 |
| | | | | | | | | 4·59 | 4·46 |

From the above group connections five conditional equations arise. We have also—

$$
\begin{array}{rcll}
\text{II} - \text{I} &=& -\,0''\!\cdot\!05 & (1891) \\
\text{III} - \text{II} &=& +\,0\cdot04 & \\
\text{IV} - \text{III} &=& -\,0\cdot25 & \\
\text{V} - \text{IV} &=& +\,0\cdot15 & \\
\text{VI} - \text{V} &=& -\,0\cdot04 & \\
\text{VII} - \text{VI} &=& +\,0\cdot17 & \\
\text{VIII} - \text{VII} &=& +\,0\cdot05 & \\
\text{I} - \text{VIII} &=& -\,0\cdot06 & \\
\text{Sum} &=& +\,\overline{0\cdot01} &
\end{array}
\qquad
\begin{array}{rcll}
\text{II} - \text{I} &=& -\,0''\!\cdot\!13 & (1892) \\
&&& \\
\text{VII} - \text{V} &=& -\,0\cdot02 & \\
&&& \\
\text{VIII} - \text{VI} &=& +\,0\cdot22 & \\
&&& \\
\text{II} - \text{VIII} &=& +\,0\cdot13 &
\end{array}
$$

In the reduction of the stars from mean to apparent place a value of 20″·445 was used for the aberration constant. The closing error of 0″·01 just given would seem to confirm this value. The effect of those terms involving the aberration constant on the group connections is as follows:

| I | II | III | IV | V | VI | VII | VIII | I | II |
|---|---|---|---|---|---|---|---|---|---|
| 4″·5 | 3″·6 | 4″·3 | 4″·0 | 4″·9 | 4″·5 | 4″·3 | 3″·5 | 5″·2 | |

The effect therefore on the group connections of using a slightly different value for $A$ would be found by multiplying these by $\frac{dA}{A}$ and we get for $A = 20''\!\cdot\!500$ the following differentials:

| I | II | III | IV | V | VI | VII | VIII | I | II |
|---|---|---|---|---|---|---|---|---|---|
| ″·012 | ″·010 | ″·012 | ″·011 | ″·013 | ″·012 | ″·012 | ″·009 | ″·014 | |

The sum of these is $0''\cdot10$, so that if we had used $20''\cdot500$ there would remain an outstanding error of $0''\cdot11$ from observation arising from the uncertainty of the group connections.

The adjusted values of the group connections furnish a means of reducing all the groups to a homogeneous system, assuming Group I as a basis of comparison. This was done, and then the weighted daily means were found. These were then collected for short intervals and we have the following table :

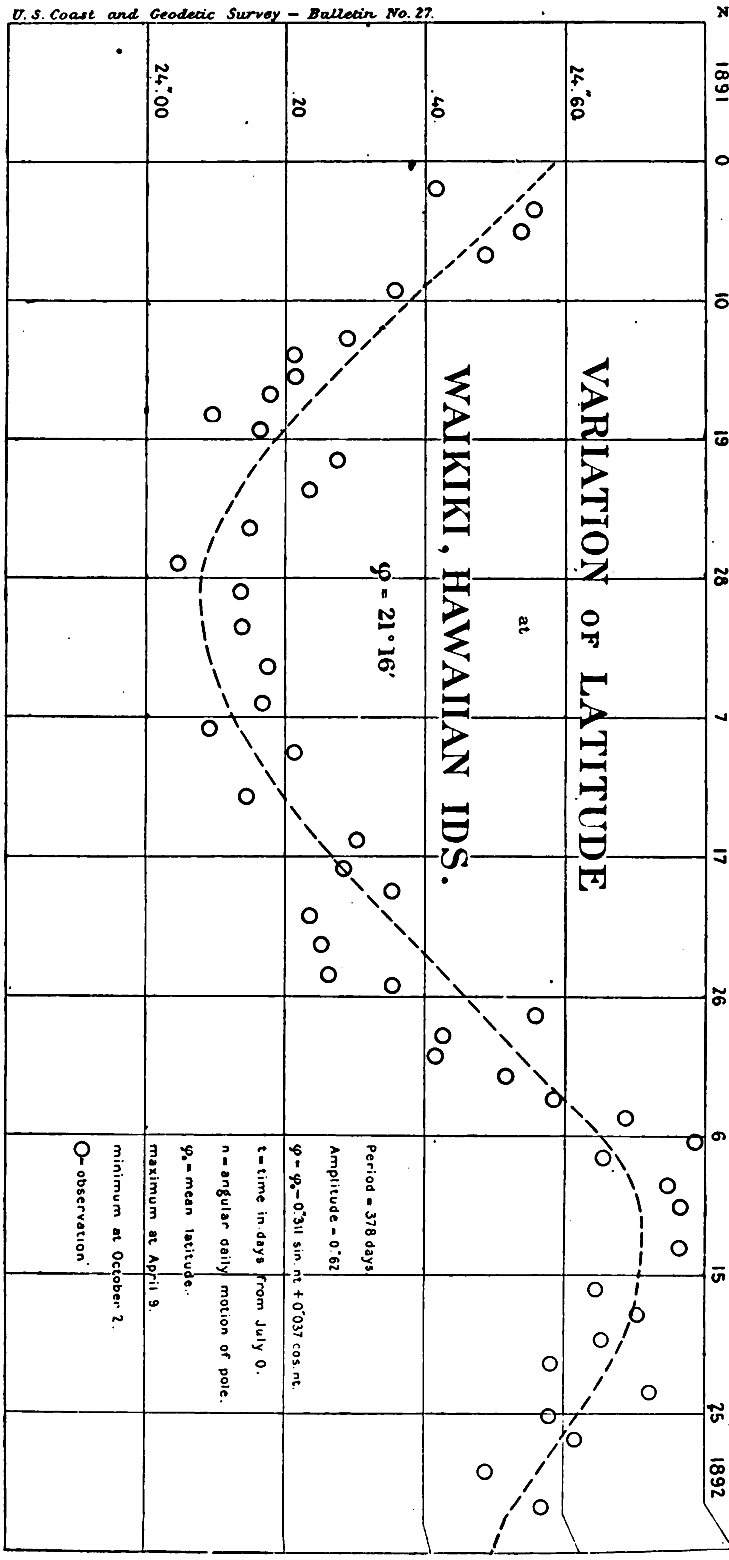
| 1891. | Latitude. | No of Pairs. | 1892. | Latitude. | No of Pairs. |
|---|---|---|---|---|---|
| | $''$ | | | $''$ | |
| June 8 | 4·41 | 48 | Jan. 2 | 4·23 | 41 |
| 14 | 4·55 | 46 | 11 | 4·25 | 55 |
| 21 | 4·53 | 51 | 20 | 4·26 | 46 |
| 27 | 4·48 | 45 | 24 | 4·35 | 44 |
| July 8 | 4·36 | 59 | 31 | 4·55 | 47 |
| 21 | 4·28 | 40 | Feb. 6 | 4·42 | 51 |
| 26 | 4·21 | 38 | 12 | 4·41 | 43 |
| Aug. 1 | 4·21 | 53 | 18 | 4·51 | 44 |
| 6 | 4·18 | 50 | 25 | 4·59 | 57 |
| 12 | 4·09 | 50 | 29 | 4·68 | 55 |
| 18 | 4·16 | 46 | Mar. 7 | 4·78 | 46 |
| 24 | 4·27 | 47 | 12 | 4·65 | 40 |
| Sept. 2 | 4·23 | 59 | 20 | 4·74 | 41 |
| 12 | 4·14 | 53 | 27 | 4·76 | 42 |
| 23 | 4·04 | 56 | Apr. 7 | 4·76 | 47 |
| Oct. 1 | 4·13 | 48 | 18 | 4·64 | 43 |
| 12 | 4·13 | 38 | 26 | 4·70 | 43 |
| 24 | 4·17 | 52 | May 3 | 4·65 | 47 |
| Nov. 3 | 4·16 | 47 | 10 | 4·57 | 49 |
| 10 | 4·09 | 45 | 18 | 4·72 | 52 |
| 18 | 4·21 | 50 | 25 | 4·58 | 45 |
| 30 | 4·14 | 50 | June 2 | 4·62 | 45 |
| Dec. 13 | 4·30 | 58 | 11 | 4·48 | 51 |
| 21 | 4·28 | 61 | 21 | 4·56 | 54 |
| 27 | 4·35 | 50 | | | |

This table is shown graphically in illustration (I).

The curve drawn is from the equation—

$$\varphi = \varphi_0 - 0''\cdot311 \text{ sin. } nt + 0\cdot037 \text{ cos. } nt,$$

which, however, does not come from a rigorous adjustment by least squares. An approximate method similar to Cauchy's was employed, which gives all the accuracy necessary for the purposes of comparison between theory and observation.


U. S. Coast and Geodetic Survey – Bulletin No. 27.
No. 1
VARIATION OF LATITUDE
at
WAIKIKI, HAWAIIAN IDS.
φ = 21° 16′
24.″60
.40
.20
24.″00
1891
June 0
July 10
Aug. 19
Sep. 28
Nov. 7
Dec. 17
Jan. 26
Mar. 6
Apr 15
May 25
1892
Period = 378 days.
Amplitude = 0.″62
φ = φ₀ − 0.″311 sin. nt + 0.″037 cos. nt.
t = time in days from July 0.
n = angular daily motion of pole.
φ₀ = mean latitude.
maximum at April 9.
minimum at October 2.
O = observation.

In order to discover any terms depending on multiple angles, the data were still further condensed by taking means of successive groups of four. This leads to the following values of the latitude:

| Date. | Latitude. | Date. | Latitude. |
|---|---|---|---|
| 1891. | $''$ | 1892. | $''$ |
| June 18 | 24·492 | Jan. 7 | 24·272 |
| July 22 | ·265 | Feb. 3 | ·432 |
| Aug 15 | ·175 | Feb. 27 | ·640 |
| Sept. 17 | ·135 | Mar. 24 | ·728 |
| Oct. 28 | ·138 | May 3 | ·656 |
| Dec. 5 | ·232 | June 7 | ·560 |

Applying Fourier's theorem

$$f\ (\varphi) = X + h_1 \sin.\ (a_1 + \varphi) + h_2 \sin.\ (a_2 + 2\varphi) + h_3 \sin.\ (a_3 + 3\varphi +)$$

we get 12 conditional equations of which the first is

$$\begin{aligned} +\ 0''{\cdot}098 = x &+ h_1 \sin.\ a_1 \cos.\ 349^\circ + h_1 \cos.\ a_1 \sin.\ 349^\circ \\ &+ h_2 \sin.\ a_2 \cos.\ 338^\circ + h_2 \cos.\ a_2 \sin.\ 338^\circ \\ &+ h_3 \sin.\ a_3 \cos.\ 327^\circ + h_3 \cos.\ a_3 \sin.\ 327^\circ \end{aligned}$$

The period is taken in this adjustment as 381 days, and the angular values are counted from July 0, 1891.

From the 12 conditional equations 7 normal equations are formed, and the values of the constants substituted in Fourier's theorem give the following equation for the variation of latitude :

$$\begin{aligned} \varphi = 24''{\cdot}386 &+ 0{\cdot}028 \cos.\ \varphi - 0''{\cdot}297 \sin.\ \varphi \\ &- \ {\cdot}039 \cos.\ 2\varphi - \ {\cdot}006 \sin.\ 2\varphi \\ &+ \ {\cdot}040 \cos.\ 3\varphi + \ {\cdot}001 \sin.\ 3\varphi \end{aligned}$$

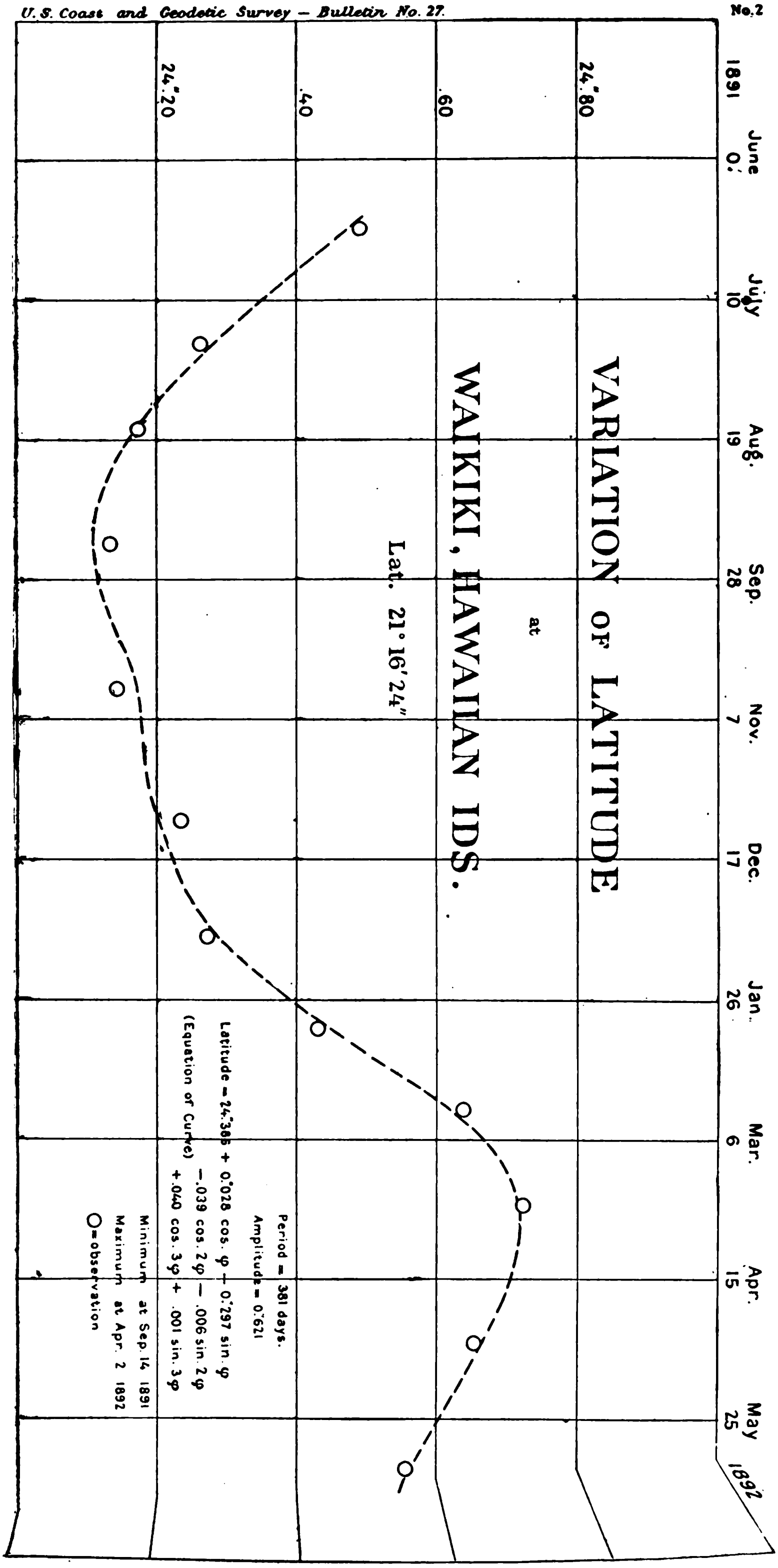
The 1st differential coefficient of this equation becomes 0 at $71^\circ{\cdot}4$ and at $261^\circ{\cdot}3$. Hence there is a minimum at September 14, 1891, and a maximum at April 2, 1892. The amplitude is $0''{\cdot}621$.

This equation is plotted in illustration (2) as well as values derived from observation.

From the residuals of the 12 conditional equations the probable error of one of them is $0''{\cdot}021$. This is computed from the formula $r = {\cdot}675 \sqrt{\dfrac{[V^2]}{m-\mu}}$ where $m$ = the number of equations of condition and $\mu$ = the number of unknown quantities determined.

The probable error of observation computed from one group observed for one month gave $r = 0''{\cdot}15$ from which the probable error of the mean of one night's work (16 pairs) would be $0''{\cdot}04$.

The Coast and Geodetic Survey Observatory was $0''{\cdot}3$ south of that of the International Association, and the system of getting the star


U. S. Coast and Geodetic Survey — Bulletin No. 27.
No. 2
VARIATION OF LATITUDE
at
WAIKIKI, HAWAIIAN IDS.
Lat. 21° 16′ 24″
24″.80
.60
.40
24″.20
1891
June 0.
July 10
Aug. 19
Sep. 28
Nov. 7
Dec. 17
Jan. 26
Mar. 6
Apr. 15
May 25
1892
Period = 381 days.
Amplitude = 0″.621
Latitude = 24″.385 + 0″.028 cos. φ + 0″.297 sin. φ
(Equation of Curve) −.039 cos. 2φ − .006 sin. 2φ
+.040 cos. 3φ + .001 sin. 3φ
Minimum at Sep. 14 1891
Maximum at Apr. 2 1892
O = observation

places in our office would place it farther south than the places derived at Berlin by $0''.2$, so that there appears a constant difference of about $0''.5$ between the determinations of Dr. Marcuse and myself.

In reducing this work I have had the help of Mr. H. F. Flynn, Mr. H. L. Stidham, and Mr. A. L. Baldwin. Sub-Assistant John Nelson aided for a short time at the beginning of the work. My acknowledgments are also due to Assistant C. A. Schott, Chief of the Computing Division, who did everything in his power to facilitate the reductions.

UNITED STATES
COAST AND GEODETIC SURVEY.

T. C. MENDENHALL,
SUPERINTENDENT.

BULLETIN No. 29.

# THE METHODS AND RESULTS

OF THE

# U. S. COAST AND GEODETIC SURVEY

AS ILLUSTRATED AT

# THE WORLD'S COLUMBIAN EXPOSITION.

1893.

Of the Bulletins already published by the Coast and Geodetic Survey, Nos. 1 to 25, inclusive, are in quarto form; have their pages numbered consecutively, and constitute Vol. I. No. 26 begins Vol. II, which will be published in octavo.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1893.

UNITED STATES
COAST AND GEODETIC SURVEY.

T. G. MENDENHALL,
SUPERINTENDENT.

BULLETIN No. 28.

# THE CONSTANT OF ABERRATION

AS DETERMINED FROM

## A DISCUSSION OF RESULTS FOR LATITUDE

AT

## WAIKIKI, HAWAIIAN ISLANDS.

A report by E. D. PRESTON, ASSISTANT.

Submitted for publication October 16, 1893.

Bulletins are issued by the Survey from time to time as material for them accumulates. They are intended to give early announcement of work accomplished or information of importance obtained, and will in many cases anticipate the usual means of publication afforded by the Annual Reports. Those already published Nos. 1 to 25 inclusive, in quarto form, have their pages numbered consecutively and constitute Vol. I. No. 26 begins Vol. II, which will be published in octavo.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1893.

2—1708

# DETERMINATION OF THE CONSTANT OF ABERRATION FROM A DISCUSSION OF THE RESULTS OF OBSERVATIONS FOR THE VARIATION OF LATITUDE AT WAIKIKI, NEAR HONOLULU, HAWAIIAN ISLANDS.

E. D. PRESTON; ASSISTANT.

The astronomical observations made at Waikiki in 1891 and 1892 showed conclusively that the latitude of this place had a periodic variation. Its value on July 0, 1891, was $21^\circ\ 16'\ 24''.41$, and for any subsequent time during the period of observation it may be found by substitution in the formula—

$$\begin{aligned} \text{Latitude} = 21^\circ\ 16'\ 24''.386 &+ 0''.028 \cos \theta - 0''.297 \sin \theta \\ &- 0.039 \cos 2\theta - 0.006 \sin 2\theta \\ &+ 0.040 \cos 3\theta + 0.001 \sin 3\theta \end{aligned}$$

where $\theta$ is the angular distance of the pole from its assumed place on July 0, on the supposition that its daily angular motion is $0^\circ.945$.

The work having come under Professor Newcomb's observation, he made the suggestion that the individual results, as already prepared for publication, should be discussed with a view of bringing out a correction to the constant of aberration.

The method proposed contemplated a simultaneous determination of the constant of aberration and the changes of latitude, and the solution was all the more desirable because recent work indicates that the usually accepted value for this constant ($20''.445$) may be improved, and also that by a combined determination we should have an independent check on the law of latitude change deduced from these same observations.

The plan to be followed in the solution was outlined by Professor Newcomb, and transmitted to the Superintendent of the Coast and Geodetic Survey in letter of January 14, 1893. On account of other duties the work could not be taken up immediately, but during the latter part of May, while on leave of absence at Spruce Grove, Pa., I formed more than two thousand of the conditional equations. The remaining ones were computed after my return, and the subnormals were derived by Mr. Moss during the month of June. After several interruptions, the subject was again taken up and prepared for publication.

The following extract is from Professor Newcomb's letter above referred to:

"*Memorandum for determining simultaneously the variation of the latitude and the constant of aberration from a homogeneous series of observations of pairs of stars with the zenith telescope, the latitude from each individual pair, using assumed declinations, having first been completely determined.*

"Let us put—

$R =$ that part of the reduction to apparent place which depends on the aberration

$$= Cc' + Dd' = h \cos (H + \alpha) \sin \delta + i \cos \delta.$$

$A = \dfrac{R + R'}{2 \times 20{\cdot}45}$ $R$ and $R'$ being the reductions for the North and South stars of a pair respectively.

$N =$ an angle increasing uniformly with the time so as to make a revolution in 386 days.*

$\varphi_1 =$ the latitude derived from a single observation of a single pair of stars.

$\varphi_0 =$ an approximate arbitrarily assumed value of the latitude to be used unchanged throughout

$$\Delta\varphi = \varphi_1 - \varphi_0.$$

"Then each individual latitude from a pair of stars will give rise to an equation of condition of the form—

$$z + x \cos N + y \sin N - A\rho = \Delta\varphi$$

where the significance of the four unknown quantities $z$, $x$, $y$, and $\rho$ are

$z =$ correction to latitude minus correction of half sum of declinations of pairs of stars, quantities which need not and can not be determined separately.

$x$ and $y =$ coefficients of periodic variation of latitude.

$\rho =$ correction to constant of aberration.

The unknown quantity $z$ will have the same value for the same pair of stars all the way through, but not for any two pairs.

"The shortest and most rigorous method of solving the equations of condition will then be this: Divide the equation into as many groups as there are pairs of stars, all the equations from each pair forming a group. From each group form the normal equations for the four unknown quantities in the usual way; supposing all the equations to be of equal weight, the normal in $z$ will be merely the sum of the group. From the normal in $z$ thus found determine $z$ as a function of the other three unkowns and of the sum of the values $\Delta\varphi$, which will be done by merely dividing the sum by the number of equations. Substitute this value of $z$ in the other three normals derived from the group, thus getting three equations; which we may call "subnormals," involving only $x$, $y$, and $\rho$. Having done this with all the groups, the sum of all the subnormals in $x$ will be the

*Note.—The author states on next page why he has taken a period of 386 days for the purposes of this discussion. Prof. Newcomb, in his letter, uses 327 days.

final normal equation for determining $x$, and so on with the other unknown quantities.

"The principle of this method differs from that of the method adopted by the Germans in two points. It assumes that, during the time of any series of observations which are combined to attain a single set of results, the changes in latitude can be represented by a single periodic term of known period. It does not assume that this law is valid outside the particular series under discussion.

"On the other hand, the German method makes no hypothesis respecting a law of variation of the latitude, except that the latitude remains constant during certain short intervals of time.

"But the present method involves a more rigorous adjustment of the declinations of the stars, since practically each star is considered independently as a group by itself. In other words the value of $z$ for each star being applied to its assumed declination, all the declinations will be reduced to a uniform comparable system."

It so happens that the period during which observations were made corresponds almost precisely to the time of revolution of the principal axis of inertia of the earth about the axis of rotation. From the day on which the first observations were made to that on which the last were made—that is, from June 6, 1891, to June 25, 1892, both inclusive—makes an interval of 386 days. This differs so little from that adopted in the discussion of the variation of latitude (381 days) (see Bulletin No. 27 U. S. Coast and Geodetic Survey), that for the sake of convenience in dealing with the circular functions, it was assumed as the period, and the initial value was placed at June 6.

The difference of apparent and adopted period, from Chandler's mean period of about 428 days, would arise from the addition of his annual term.

The entire series gives rise to 2 370 conditional equations distributed by pairs and groups as follows:

GROUP.

| PAIR. | I | II | III | IV | V | VI | VII | VIII |
|---|---|---|---|---|---|---|---|---|
| 1 | 43 | 45 | 31 | 33 | 31 | 38 | 39 | 42 |
| 2 | 54 | 45 | 37 | 33 | 37 | 38 | 44 | 39 |
| 3 | 55 | 36 | 37 | 32 | 34 | 39 | 42 | 39 |
| 4 | 55 | 42 | 35 | 31 | 29 | 38 | 40 | 43 |
| 5 | 56 | 36 | 33 | 29 | 33 | 38 | 40 | 37 |
| 6 | 50 | 33 | 33 | 32 | 32 | 35 | 39 | 34 |
| 7 | 51 | 37 | 32 | 32 | 31 | 36 | 34 | 37 |
| 8 | ...... | 33 | 36 | 30 | 30 | 33 | 33 | 39 |
| Sums | 364 | 307 | 274 | 252 | 257 | 295 | 311 | 310 |

**The different groups will be designated by Roman numerals and the individual pairs by Arabic subscripts; e. g., the fifth pair of the third group is $III_5$.**

The observation of $I_1$ on June 7, 1891, gave for $\varphi_1$ the value $24''\cdot67$; $\varphi_0$ is taken as $24''\cdot00$, and we therefore have $\Delta\varphi = \varphi_1 - \varphi_0 = +0''\cdot67$. The angular distance traveled by the pole since June 6 is $0^\circ\cdot933$, and hence $\cos N = +1\cdot00$ and $\sin N = +0\cdot02$.

The positions of the two stars forming this pair were:

| | Right Ascension. h. | m. | s. | Declination. ° | ′ |
|---|---|---|---|---|---|
| $I_{1a}$ | 13 | 27 | 46 | −7 | 4 |
| $I_{1b}$ | 13 | 30 | 5 | +49 | 34 |

and the values of $h \cos(H + \alpha) \sin\delta + i \cos\delta = R$ for the first and second stars respectively are:

$$-3''\cdot87 \text{ and } +11''\cdot63$$

from which $A = +0\cdot19$.

The conditional equation for June 7 and for the observation on $I_1$ is therefore

$$z + 1\cdot00\,x + 0\cdot02\,y + 0\cdot19\,\rho = +0''\cdot67.$$

For facility of computation, instead of using the equation in the form given by Professor Newcomb, on page 3, $+A$ was used instead of $-A$. This amounts to changing $\rho$ into $-\rho$; that is, taking $\rho$ as the negative of the correction to the constant of aberration.

In this way an equation of condition was formed for each one of the individual results for the latitude, making, as tabulated above, an aggregate of 2 370 equations, containing four unknown quantities and known terms.

The method of dividing these equations into blocks for short intervals is shown by the following table, where all the observations on the first pair of Group I are used and the partial sum is derived for the first block preparatory to forming the subnormal equations. This division into blocks was made to save the labor of forming the products of the coefficients for each separate equation. A final result is obtained, which is, with only insignificant errors, the same as if each equation had been multiplied separately:

$I_1$.—1891.

| | | | | | ″ |
|---|---|---|---|---|---|
| June 7 | $z$ | $+1\cdot00\,x$ | $+0\cdot02\,y$ | $+0\cdot19\,\rho$ | $=+0\cdot67$ |
| 8 | | $+1\cdot00$ | $+\cdot03$ | $+\cdot20$ | $=-\cdot16$ |
| 9 | | $+1\cdot00$ | $+\cdot05$ | $+\cdot21$ | $=+\cdot84$ |
| 11 | | $+1\cdot00$ | $+\cdot08$ | $+\cdot22$ | $=+\cdot14$ |
| | $4z$ | $+4\cdot00\,x$ | $+0\cdot18\,y$ | $+0\cdot82\,\rho$ | $=+1\cdot49$ |
| 13 | $z$ | $+0\cdot99\,x$ | $+0\cdot11\,y$ | $+0\cdot24\,\rho$ | $=+0\cdot82$ |
| 15 | | $+\cdot99$ | $+\cdot15$ | $+\cdot25$ | $=+\cdot50$ |
| 16 | | $+\cdot99$ | $+\cdot16$ | $+\cdot26$ | $=+\cdot58$ |
| 17 | | $+\cdot98$ | $+\cdot18$ | $+\cdot27$ | $=+\cdot75$ |
| 18 | | $+\cdot98$ | $+\cdot19$ | $+\cdot28$ | $=+\cdot12$ |
| 22 | | $+0\cdot97\,x$ | $+0\cdot26\,y$ | $+0\cdot30\,\rho$ | $=+0\cdot81$ |
| 26 | | $+\cdot95$ | $+\cdot32$ | $+\cdot33$ | $=+\cdot26$ |

I₁.—1892.

| | | | | |
|---|---|---|---|---|
| | | | | ″ |
| April 9 | $z$ + 0·30 $x$ | − 0·95 $y$ | − 0·30 $\rho$ | = + 1·32 |
| 19 | + ·45 | − ·89 | − ·23 | = + 0·88 |
| 24 | + ·52 | − ·85 | − ·18 | = + 1·12 |
| 25 | + ·53 | − ·85 | − ·18 | = + 1·34 |
| | | | | |
| May 1 | $z$ + 0·61 $x$ | − 0·79 $y$ | − 0·13 $\rho$ | = + 1·08 |
| 4 | + ·65 | − ·76 | − ·10 | = + 0·22 |
| 5 | + ·66 | − ·75 | − ·09 | = + 1·07 |
| 9 | + ·71 | − ·70 | − ·06 | = + 0·56 |
| 10 | + ·72 | − ·69 | − ·05 | = + 0·84 |
| 13 | + ·76 | − ·65 | − .02 | = + 0·64 |
| | | | | |
| 14 | $z$ + 0.77 $x$ | − 0·64 $y$ | − 0·01 $\rho$ | = + 0·52 |
| 15 | + .78 | − ·63 | ·00 | = + 0·87 |
| 18 | + ·81 | − ·59 | + ·02 | = + 1·30 |
| 21 | + ·83 | − ·55 | + ·05 | = + 0·86 |
| 22 | + .84 | − ·54 | + ·06 | = + 1·03 |
| | | | | |
| 24 | $z$ + 0·86 $x$ | − 0·51 $y$ | + 0·08 $\rho$ | = + 0·78 |
| 25 | + ·87 | − ·50 | + ·09 | = + 0·70 |
| 26 | + ·87 | − ·48 | + ·09 | = + 0·34 |
| 28 | + ·89 | − ·45 | + ·11 | = + 0·64 |
| 29 | + ·90 | − ·44 | + ·12 | = + 1·10 |
| | | | | |
| June 3 | $z$ + 0·93 $x$ | − 0·36 $y$ | + 0·16 $\rho$ | = + 0·52 |
| 4 | + ·94 | − ·35 | + ·17 | = + ·90 |
| 5 | + ·94 | − ·33 | + ·18 | = + ·82 |
| 7 | + ·95 | − ·20 | + ·20 | = + ·42 |
| | | | | |
| 11 | $z$ + 0·97 $x$ | − 0·24 $y$ | + 0·23 $\rho$ | = + 0·90 |
| 13 | + ·98 | − ·21 | + ·24 | = + ·07 |
| 17 | + ·99 | − ·14 | + ·27 | = + ·62 |
| | | | | |
| 18 | $z$ + 0·99 $x$ | − 0·13 $y$ | + 0·28 $\rho$ | = + 1·18 |
| 19 | + 0·99 | − ·11 | + ·29 | = + 1·14 |
| 22 | + 1·00 | − ·06 | + ·31 | = + ·65 |
| 24 | + 1·00 | − .03 | + ·32 | = + ·52 |
| 25 | + 1·00 | − ·01 | + ·33 | = + ·74 |

A similar summary was made for each pair, the blocks being chosen to conveniently fit the dates of observation. The block interval rarely exceeded ten days. The total number of these block equations is 534.

From these tables the subnormals were formed according to the following scheme:

Compartment $A$ contains the "block equations," the first of which has been previously given. In $B$ are found the mean equations corresponding line for line with $A$, from which they were derived.

Compartment $C$ is deduced by multiplying the coefficent of $x$ in $B$ by the corresponding equations in $A$.

In $D$ we have the equations resulting from multiplying the coefficients of $y$ in $B$ by the corresponding equation in $A$, and $E$ comes from a similar use of the coefficient of $\rho$ in $B$.

It is evident that by multiplying the coefficients of $x$ in $B$ by the coefficients of $z$ in $A$ we get the coefficients of $x$ in $A$, so that the first column of $C$ is the same as the second column of $A$, and it is therefore not written in compartment $C$.

Likewise by multiplying the coefficients of $y$ in $B$ by the coefficients of $z$ in $A$ we get the coefficients $y$ in $A$, i. e., the third column in $A$, so that the first column in $D$ is the same as the third column of $A$; also the coefficients of $y$ in $B$ by those of $x$ in $A$ give the coefficients of $y$ in $C$, i. e., the third column of $C$ (first column of $C$ is unwritten) so that the second column of $D$ is the same as the third column of $C$ and is not put down.

The products of the coefficients of $y$ in $B$ by those of $y$ in $A$ give the third column in $D$ (first written one), and the coefficients of $\rho$ in $B$ by those of $\rho$ in $A$ give the fourth column in $D$.

$E$ is formed in the same way by multiplying the coefficients of $\rho$ in $B$ by the corresponding equations in $A$, it only being necessary to begin writing down the products derived from the coefficients of $\rho$ in $B$, by those of $\rho$ in $A$.

In regard to the right-hand members of the equations in the several compartments, they are derived from the right hand members of $A$ by the same process; that is to say, the multiplication of the several coefficients of $B$ is extended to the known members of $A$ to get the corresponding members $C$, $D$, and $E$.

## $I_1$.—FORMATION OF SUBNORMALS FOR PAIR NO. 1.

### A.

| | | | | |
|---|---|---|---|---|
| $4z$ | $+\,4·00\,x$ | $+\,·18\,y$ | $+\,0·82\,\rho$ | $=+\,1·49$ |
| 5 | + 4·93 | + ·79 | + 1·30 | = + 2·77 |
| 2 | + 1·92 | + ·58 | + 0·63 | = + 1·07 |
| 4 | + 1·80 | − 3·54 | − 0·89 | = + 4·66 |
| 6 | + 4·11 | − 4·34 | − 0·45 | = + 4·41 |
| 5 | + 4·03 | − 2·95 | + 0·12 | = + 4·58 |
| 5 | + 4·39 | − 2·38 | + 0·49 | = + 3·56 |
| 4 | + 3·76 | − 1·34 | + 0·71 | = + 2·66 |
| 3 | + 2·94 | − 0·59 | + 0·74 | = + 1·59 |
| 5 | + 4·98 | − 0·34 | + 1·53 | = + 4·23 |
| (a) 43 | + 36·86 | − 13·93 | + 5·00 | = + 31·02 |
| 1 | + ·857 | − ·324 | + ·116 | = + ·72 |

### B.

| | | | | |
|---|---|---|---|---|
| $z$ | $+\,1·000\,x$ | $+\,·045\,y$ | $+\,·205\,\rho$ | $=+\,·372$ |
| | + ·986 | + ·158 | + ·260 | = + ·554 |
| | + ·960 | + ·290 | + ·315 | = + ·535 |
| | + ·450 | − ·885 | − ·222 | = + 1·165 |
| | + ·685 | − ·723 | − ·075 | = + ·735 |
| | + ·806 | − ·590 | + ·024 | = + ·916 |
| | + ·878 | − ·476 | + ·098 | = + ·712 |
| | + ·940 | − ·335 | + ·178 | = + ·665 |
| | + ·980 | − ·197 | + ·247 | = + ·530 |
| | + ·996 | − ·068 | + ·306 | = + ·846 |

### C.

| | | | | |
|---|---|---|---|---|
| | + 4·00 | + ·18 | + ·82 | = + 1·49 |
| | + 4·86 | + ·78 | + 1·28 | = + 2·73 |
| | + 1·84 | + ·56 | + ·60 | = + 1·03 |
| | + 0·81 | − 1·59 | − ·40 | = + 2·10 |
| | + 2·82 | − 2·97 | − ·31 | = + 3·02 |
| | + 3·25 | − 2·38 | + ·10 | = + 3·69 |
| | + 3·85 | − 2·09 | + ·43 | = + 3·18 |
| | + 3·53 | − 1·26 | + ·67 | = + 2·50 |
| | + 2·88 | − 0·58 | + ·73 | = + 1·56 |
| | + 4·96 | − 0·34 | + 1·52 | = + 4·21 |
| (c) (+ 36·86) | + 32·80 | − 9·69 | + 5·44 | = + 25·46 |
| (+ 36·86) | + 31·59 | − 11·94 | + 4·28 | = + 26·58 |
| | + 1·21 | + 2·25 | + 1·16 | = − 1·12 |

### D.

| | | | | |
|---|---|---|---|---|
| | | + ·01 | + ·04 | = + ·07 |
| | | + ·12 | + ·21 | = + ·44 |
| | | + ·17 | + ·18 | = + ·31 |
| | | + 3·13 | + ·79 | = − 4·12 |
| | | + 3·14 | + ·33 | = − 3·19 |
| | | + 1·74 | − ·07 | = − 2·70 |
| | | + 1·13 | − ·23 | = − 1·69 |
| | | + 0·45 | − ·24 | = − 0·89 |
| | | + 0·12 | − ·15 | = − 0·31 |
| | | + 0·02 | − ·10 | = − 0·29 |
| (d) (− 13·93) | − (9·69) | + 10·03 | + ·76 | = − 12·37 |
| (− 13·93) | − (11·94) | + 4·51 | − 1·62 | = − 10·04 |
| | + 2·25 | + 5·52 | + 2·38 | = − 2·33 |

### E.

| | |
|---|---|
| + ·17 | + ·31 |
| + ·34 | + ·72 |
| + ·20 | + ·34 |
| + ·20 | − 1·03 |
| + ·03 | − ·33 |
| + ·00 | + ·11 |
| + ·05 | + ·35 |
| + ·13 | + ·47 |

| | | | | |
|---|---|---|---|---|
| | | | + ·18 | + ·39 |
| | | | + ·47 | + 1·29 |
| (e) (+ 5·00) | + (5·44) | + (·76) | + 1·77 | = + 2·62 |
| (+ 5·00) | + (4·29) | − (1·62) | + ·58 | = + 3·61 |
| | + (1.15) | + (2·38) | + 1·19 | = − ·99 |

The subnormals from the first pair of Group I are, therefore—

$$
\begin{array}{llll}
+1{\cdot}21\,x & +2{\cdot}25\,y & +1{\cdot}16\,\rho & = -1{\cdot}12'' \\
+2{\cdot}25 & +5{\cdot}52 & +2{\cdot}38 & = -2{\cdot}33 \\
+1{\cdot}16 & +2{\cdot}38 & +1{\cdot}19 & = -0{\cdot}99
\end{array}
$$

The total number of subnormal equations is 189.

The quantities inclosed in brackets are, for the upper line, the sums of the blank columns, which, in a full scheme, would be written above them, and for the lower line the coefficients arising from the elimination of $z$ by means of equation ($a$); for example, the lower line of ($c$) is obtained by multiplying the lower line of ($a$) by 36·86; the lower line of ($d$) by multiplying the lower line of ($a$) by (— 13·93), etc. These quantities in brackets are not necessary for the computation, but serve as a partial check on the side coefficients of the resulting subnormals.

The following are the mean subnormals for the respective groups:

MEAN SUBNORMALS IN $x$.

| GROUP. | | | | |
|---|---|---|---|---|
| I | + 1·47 $x$ | + 2·83 $y$ | + 1·64 $\rho$ | = − 0·54 |
| II | + 1·51 | − 2·64 | − 1·72 | = + 1·21 |
| III | + 3·82 | − 1·37 | − 1·96 | = + 0·49 |
| IV | + 4·96 | + 1·96 | − 1·18 | = + 0·45 |
| V | + 1·07 | + 1·89 | − 0·01 | = − 0·35 |
| VI | + 1·05 | − 2·01 | − 0·21 | = + 0·33 |
| VII | + 4·00 | − 2·48 | + 0·50 | = + 2·33 |
| VIII | + 7·83 | + 1·12 | + 3·16 | = + 0·65 |

MEAN SUBNORMALS IN $y$.

| GROUP. | | | | |
|---|---|---|---|---|
| I | + 2·83 $x$ | + 7·76 $y$ | + 3·71 $\rho$ | = − 1·38 |
| II | − 2·64 | + 7·40 | + 4·25 | = − 2·54 |
| III | − 1·37 | + 0·68 | + 0·84 | = − 0·31 |
| IV | + 1·96 | + 0·99 | − 0·36 | = + 0·12 |
| V | + 1·89 | + 4·55 | + 0·26 | = − 0·82 |
| VI | − 2·01 | + 5·21 | + 0·48 | = − 0·96 |
| VII | − 2·48 | + 1·87 | − 0·28 | = − 1·65 |
| VIII | + 1·12 | + 0·61 | + 0·58 | = − 0·14 |

MEAN SUBNORMALS IN $\rho$.

| Group. | | | | |
|---|---|---|---|---|
| I | + 1·64 $x$ | + 3·71 $y$ | + 2·06 $\rho$ | = − 0.64 |
| II | − 1·72 | + 4·25 | + 2·59 | = − 1·59 |
| III | − 1·96 | + 0·84 | + 1·09 | = − 0·33 |
| IV | − 1·18 | − 0·36 | + 0·33 | = − 0·14 |
| V | − 0·01 | + 0·26 | + 0·06 | = − 0·03 |
| VI | − 0·21 | + 0·48 | + 0·05 | = − 0·10 |
| VII | + 0·50 | − 0·28 | + 0·08 | = + 0·29 |
| VIII | + 3·16 | + 0·58 | + 1·32 | = + 0·18 |

From the 63 groups of subnormals we deduce the following normal equations in $x, y$, and $\rho$.

$$
\begin{aligned}
+\ 204{\cdot}2\ x - 8{\cdot}44\,y + 0{\cdot}11\,\rho &= +\ 37{\cdot}12 \\
-\ 8{\cdot}44\,x + 224{\cdot}8\ y + 71{\cdot}94\,\rho &= -\ 60{\cdot}07 \\
+\ 0{\cdot}11\,x + 71{\cdot}94\,y + 58{\cdot}50\,\rho &= -\ 18{\cdot}29
\end{aligned}
$$

from which $x = +\ 0{\cdot}17$

$y = -\ 0{\cdot}26$

$\rho = +\ 0{\cdot}012$

The coefficient $A$ having been used with a reversed sign throughout, the value of $\rho$ to be applied to the constant of aberration is

$$-\ 0{\cdot}012,$$

and the result is—

Constant of aberration $= 20''{\cdot}445 - 0''{\cdot}012 = 20''{\cdot}433$.

AGREEMENT OF CURVE WITH OBSERVATION.

By substitution in the normal equations for $z$ we get the values of this quantity corresponding to the 63 different pairs of stars. The following are the mean values of $z$ for each group:

| | | |
|---|---|---|
| Group I | + | 0''·35 |
| II | + | ·26 |
| III | + | ·31 |
| IV | + | ·15 |
| V | + | ·31 |
| VI | + | ·20 |
| VII | + | ·40 |
| VIII | + | ·44 |
| Mean = | + | 0·30 |

In order to compare the results of the present investigation with those derived by treating the observations according to Albrecht's

method (U. S. C. and G. Survey Bulletin No. 27), it must be borne in mind that the values given on page 16 of the Bulletin have not only been reduced to a mean declination system for each particular group, but all the groups have, moreover, been compared with the first one, taken as a standard, and corrected accordingly.

These corrections deduced from the least square adjustment were as follows:

| | | |
|---|---|---|
| Group I | | $0''.00$ |
| II | + | .07 |
| III | + | .03 |
| IV | + | .28 |
| V | + | .12 |
| VI | + | .18 |
| VII | + | .02 |
| VIII | − | .04 |

It is therefore necessary, in applying our present curve to the diagram on page 17 of Bulletin No. 27, to increase the mean value of $z$ by the mean of the quantities just given and we have, as a result

$$z = +0.38$$

so that the equation

$$z + x \cos N + y \sin N + A\,\rho = \Delta\varphi = \varphi_1 - \varphi_0$$

for June 20, 1891 would be

$$+0.38 + 0.17 \cos 13^\circ - 0.26 \sin 13^\circ + 0.11\,(+.01) = \varphi_1 - 24''.00$$

$$\text{or } 24.48 = \varphi_1.$$

The values for succeeding dates will be modified by the periodic terms of the variation of the latitude and by the different values for $A$. The following are the mean values of $A$ for the respective groups:

| | | |
|---|---|---|
| Group I | + | $0''.09$ |
| II | + | .23 |
| III | + | .44 |
| IV | + | .48 |
| V | + | .35 |
| VI | + | .06 |
| VII | − | .14 |
| VIII | − | .17 |
| Mean | + | 0.17 |

By using mean value for $A$ the plotted curve will never be in error more than $0''.01$, which may be overlooked in the comparison of theory and observation.

As the object of this paper is primarily to bring out the constant of aberration and the variation of latitude simultaneously, it is not thought worth while to replot the original observations for comparison with our newly determined curve. The curve is simply displaced by a constant quantity which adapts it to the adjusted values in Bulletin No. 27.

The agreement is shown equally well whether we apply the curve to the original observations or whether the corrected curve is applied to the adjusted observations. The values of the latitude, therefore, on a scale comparable with those of page 16 of Bulletin No. 27, are as follows:

| Date. | Latitude. | Date. | Latitude. |
|---|---|---|---|
| 1891. | ″ | 1892. | ″ |
| June 20 | 24·48 | Jan. 6 | 24·31 |
| July 10 | ·39 | Jan. 26 | ·42 |
| July 30 | ·29 | Feb. 15 | ·50 |
| Aug. 19 | ·20 | Mar. 6 | .57 |
| Sept. 8 | .13 | Mar. 26 | ·65 |
| Sept. 28 | ·08 | Apr. 15 | ·68 |
| Oct. 18 | ·07 | May 5 | ·68 |
| Nov. 7 | ·09 | May 25 | ·66 |
| Nov. 27 | ·14 | June 14 | ·60 |
| Dec. 17 | ·21 | | |

These values correspond to the dotted curve in Fig. 1. The small circles are the results from observations on the same scale, and the lower curve is the one derived in Bulletin No. 27. It appears that Newcomb's method, in addition to a determination of the aberration constant, brings out simultaneously the periodic variation of the latitude, agreeing practically with the results from Albrecht's method. The period is slightly different in the two treatments.

### PROBABLE ERROR OF OBSERVATION.

Without attempting to calculate the residuals from the 2 370 conditional equations, we can arrive at a very close approximation to the probable error of observation by selecting a few representative groups. The time from the beginning of July, 1891, to the beginning of June, 1892, is almost completely covered by the work in Groups III, V, and VIII, so that the probable error from these groups may fairly be taken as involving those conditions such as temperature, humidity, etc., which influence errors of observation.

By substituting in all the conditional equations for III, V, and VIII, we get the following probable errors of observation:

| Group. | No. of Conditional Equations. | Probable Errors of Observation. |
|---|---|---|
| | | $''$ |
| II | 274 | 0·312 |
| V | 257 | 0·283 |
| VIII | 310 | 0·295 |
| | | 0·297 |

Taking a mean value we assume the probable error of observation to be

$$0''\cdot297.$$

This includes the probable error of declination, which has an average value of $0''\cdot257$ for the 63 pairs.

The weights of the quantities $x, y$, and $\rho$ are found by writing $-1$ for the absolute term of the normal equation in $x$ and zero for the absolute term in the remaining two, and solving and continuing this process for each unknown quantity.

The result is

$$\text{Weights of } x = 204$$
$$y = 137$$
$$\rho = 35$$

and the probable errors are

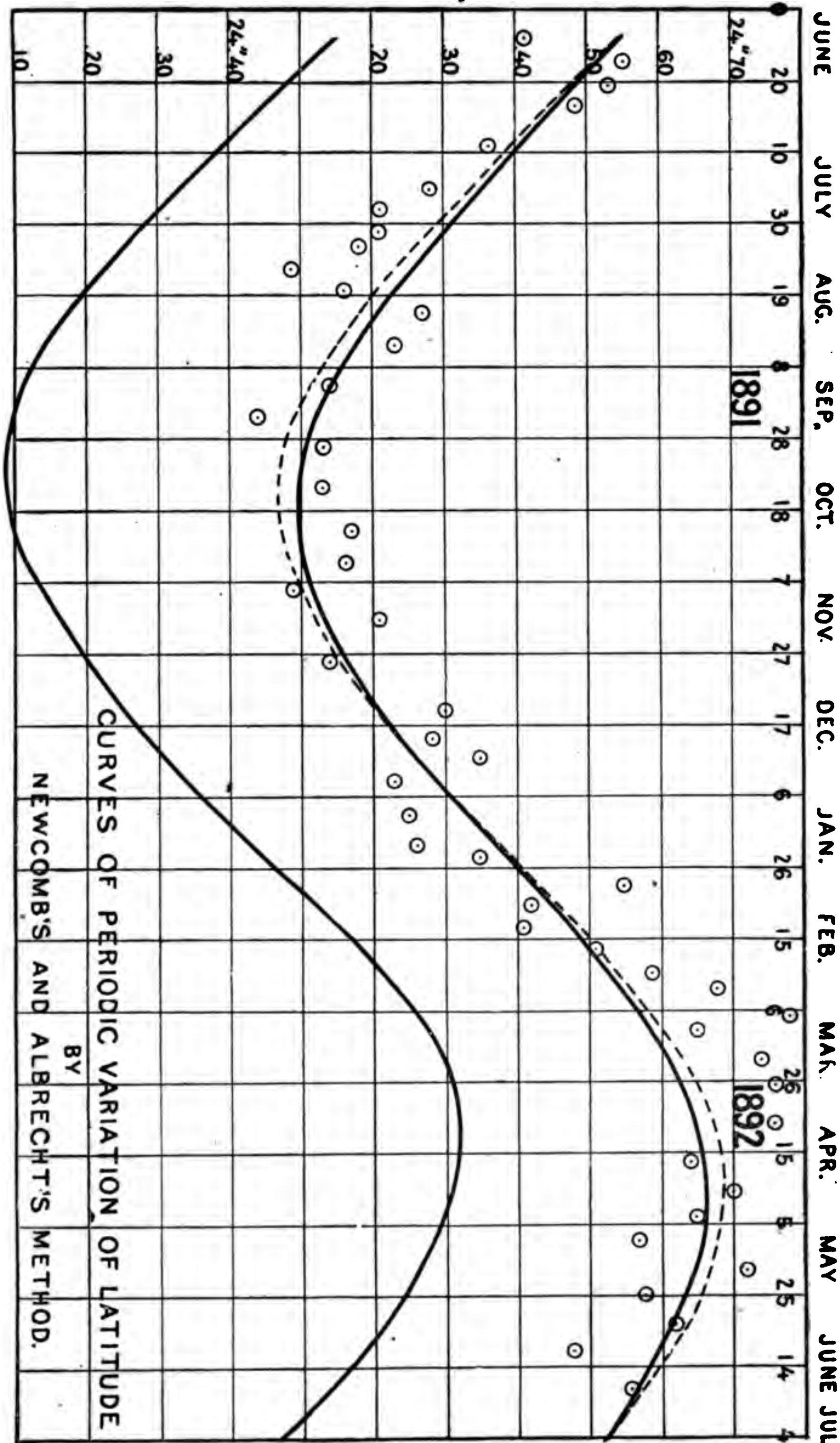
$$\epsilon_x = \frac{\epsilon}{\sqrt{p_x}} = \frac{0\cdot297}{14\cdot3} = \cdot021 \text{ and } r_x = \pm\cdot014.$$
$$\epsilon_y = \frac{\epsilon}{\sqrt{p_y}} = \frac{0\cdot297}{11\cdot7} = \cdot025 \qquad r_y = \pm\cdot017.$$
$$\epsilon_\rho = \frac{\epsilon}{\sqrt{p_\rho}} = \frac{0\cdot297}{5\cdot9} = \cdot050 \qquad r_\rho = \pm\cdot034.$$

The definitive result of the constant of aberration from the latitude observations of 1891–1892, made at Waikiki, Hawaiian Islands, on the part of the United States Coast and Geodetic Survey, is therefore

$$\text{Constant of aberration} = 20''\cdot433 \pm 0''\cdot034.$$

This value of the aberration constant, combined with the latest determinations of the velocity of light (V = 186 330 miles) and Clarke's value for the earth's radius (R = 3963·30 miles), gives the sun's distance and equatorial horizontal parallax as follows:

$$\text{Distance} = 92\,709\,000 \text{ miles.}$$
$$\text{Parallax} = 8''\cdot82.$$


JUNE JULY AUG. SEP. OCT. NOV. DEC. JAN. FEB. MAR. APR. MAY JUNE JULY
20 10 30 19 8 28 18 7 27 17 6 26 15 6 26 15 5 25 14 4
24."70 60 50 0.40 30 20 24."40 30 20 10
1891
1892
CURVES OF PERIODIC VARIATION OF LATITUDE
BY
NEWCOMB'S AND ALBRECHT'S METHOD.

UNITED STATES
COAST AND GEODETIC SURVEY.

T. C. MENDENHALL,
SUPERINTENDENT.

---

BULLETIN NO. 29.

---

# THE METHODS AND RESULTS

OF THE

# U. S. COAST AND GEODETIC SURVEY

AS ILLUSTRATED AT

# THE WORLD'S COLUMBIAN EXPOSITION.

1893.

---

**Of the Bulletins already published by the Coast and Geodetic Survey, Nos. 1 to 25, inclusive, are in quarto form; have their pages numbered consecutively, and constitute Vol. I. No. 26 begins Vol. II, which will be published in octavo.**

---

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1893.

# THE METHODS AND RESULTS OF THE U. S. COAST AND GEODETIC SURVEY, AS ILLUSTRATED BY ITS EXHIBIT AT THE WORLD'S COLUMBIAN EXPOSITION, 1893.

---

## UNITED STATES COAST AND GEODETIC SURVEY,

WASHINGTON, D. C., *December*, 1893.

The leaflets descriptive of the Exhibit of the Survey at the World's Columbian Exposition which are here bound together, were first published separately for distribution to visitors to the Exposition who took a special interest in the work of the Survey.

It will be seen on inspection that they are intended to present concise statements relating to the origin of the Survey; to the general plan of its operations; to the methods and processes whereby the the work is carried on, and to some of the more important results reached in its progress.

The demand for these leaflets has been so great that three editions of 5 000 copies each have been exhausted, and in order to preserve them in a permanent form it has been deemed advisable to publish them as a Bulletin.

# CONTENTS.

# UNITED STATES COAST AND GEODETIC SURVEY.

**T. C. MENDENHALL, Superintendent.**

## THE U. S. COAST AND GEODETIC SURVEY.

To all nations whose territory touches the sea or other water navigable to any extent, or who have any interests in the commerce of the sea, a full and complete knowledge of the coast—its nature and form, the character of the sea bottom near it, the location of reefs, shoals, and other dangers to navigation, the direction and strength of currents, and the character and amount of magnetic disturbance—is of the greatest moment.

To supply this knowledge the governments of all maritime nations have in modern times executed surveys of their coasts by the most exact methods.

Some idea of the importance to this country of like operations and their extent may be formed when it is remembered that the shore line of the United States, as surveyed, includes about 30,000 miles, not counting Alaska, which of itself is several times as extensive.

On the recommendation of President Thomas Jefferson, Congress, in 1807, authorized the establishment, as a Bureau under the Secretary of the Treasury, of a National Coast Survey. For the purpose of furnishing geographical positions and other data to State surveys the scope of the Bureau was, in 1878, enlarged and its designation became the U. S. Coast and Geodetic Survey.

The plan upon which it is organized is the outgrowth of trial and experience during the first fifty years of its existence, and from its inception almost every year has seen some new feature added, or some old one discarded.

Under the direction of a Superintendent there are two great divisions of its work. They are the field and the office.

The field work includes all of the practical operations of the Survey on land and sea. Work upon the land is directly conducted by a body of trained civilian experts, permanently attached to the Survey, and numbering between fifty and sixty.

The hydrographic work is in general conducted by naval officers, temporarily detailed to the Survey, their connection with it usually lasting about three years.

Special hydrographic work is sometimes executed by members of the civilian staff.

The service owns a fleet of about fifteen vessels, eight of which are steamers.

The office is that part of the establishment which receives the records, original sheets, etc., representing the results of field work. They are registered and deposited in the archives until in turn they are taken up for examination, computation, and adjustment, prepared for publication, and finally published. Original charts are reduced or enlarged, engraved, electrotyped, and printed.

For the convenience of administration, the operations of the main office at Washington are carried on by ten divisions, each having some specified portion of the general work to perform. In these divisions are employed the required force of clerks, draughtsmen, computers, engravers, instrument makers, printers, etc., numbering in all about 135.

There are sub-offices at San Francisco and Philadelphia.

All of the field operations of the Survey being geodetic in their nature, a system of primary triangulation together with the determination of geographical positions by means of astronomical methods, must furnish the foundation upon which the whole rests. On the Atlantic coast a chain of triangles, beginning at the eastern boundary of Maine, stretches nearly to the Gulf, constituting an oblique arc, which, besides serving as a basis for the coast triangulation, will, when

entirely completed and discussed, add much to our knowledge of the figure of the earth.

An extensive system of triangles, to extend across the continent along the 39th parallel of latitude, is now rapidly approaching completion.

In connection with these principal systems the triangulation has been considerably expanded in the New England States, New York, and several western States, including California, where some exceptionally large figures were introduced. The longest line so far observed is that from Mount Helena to Mount Shasta, over one hundred and ninety miles in length.

A tertiary triangulation for topographic and hydrographic purposes has been completed along the entire Atlantic and Gulf coasts, and over more than half of the Pacific coast, except Alaska. Much progress has been made in the latter territory by methods which, while they are more in the nature of a reconnaissance than anything else, possess a sufficient degree of accuracy for immediate use and are capable of rapid execution.

In the determination of astronomical positions, the exact methods originally developed in the Survey have been adhered to and perfected. The methods of using the zenith telescope for latitude, and the telegraph for longitude, have been constantly improved.

The topographical operations have been mostly restricted to a narrow margin, not often over three to five miles wide, along the coast and surrounding harbors, bays, and rivers up to the head of tidewater. In some cases it has been somewhat more extensive, notably in the survey of the District of Columbia, just completed, where the scale was $\frac{1}{4800}$, and the contour interval only five feet.

The hydrographic operations have extended as far out from the coast as was necessary for the interests of navigation, and have included all harbors, channels, bays, etc., as far as the work has gone.

Deep-sea soundings have been made extensively, especially in and about the Gulf Stream.

Much attention has been given to tides, and continuous series of tidal records have been maintained at several important points.

The results of the operations of the Survey in connection with the study of terrestrial magnetism can be found on its charts, and in its

other numerous publications on the subject. In addition to the determination of the magnetic elements at many widely distributed points and their frequent redetermination for secular variation, it has long maintained a photographic registering magnetic observatory, which is moved from one part of the country to another, remaining a series of years at one point.

The study of the force of gravity, as a part of the great geodetic problem, has received its attention for twenty years, and it has recently developed methods and instruments which will lead to a great extension of the work, at a less cost than by older processes, but without lowering the standard of accuracy.

A system of precise geodetic leveling extending across the continent, nearly in the line of the great chain of triangles, and checked by lines extending to the Gulf, the great lakes, and in other directions, is being executed and has brought forth results of great interest.

Throughout its history the Survey has constantly been called upon to determine boundary lines which have been in dispute.

At the present time, with its assistance, two National and two State boundaries are in the process of settlement.

Under the direction of the Superintendent is also the Office of Standard Weights and Measures, which is charged with the maintenance of the standards of length, weight, and capacity. Upon its operations depend the accuracy of all measures throughout the United States.

The principal publications of the Survey consist of about five hundred different charts; tide tables for all the principal and many minor ports; a monthly edition of 10,000 copies of a circular known as "Notices to Mariners", containing notes of all changes along the coast; Coast Pilots, containing minute sailing directions for all navigable waters along our coast; and the Report of the Coast and Geodetic Survey, which contains, besides the reports of the Superintendent and his assistants on the conduct of the work, a series of special reports upon various technical and scientific operations of the service.

WASHINGTON, D. C.,
*May* 1, 1893.

# UNITED STATES COAST AND GEODETIC SURVEY.

**T. C. MENDENHALL, Superintendent.**

## BASE APPARATUS.

---

In applications of the sciences of surveying and geodesy it is often essential to measure lines of greater or less length along the surface of the earth. Thus, in land surveying, the lengths of the bounding lines of farms, lots, etc., are measured in order that their areas may be calculated and their metes and bounds defined, and in railway and canal surveying, many distances are measured in order that the relative positions of points may be known, and that the cubical contents of excavations and embankments may be computed. But it often happens that the direct measurement of a line is impracticable or impossible; as, for example, a line across a river, across a lake, or across a valley from one mountain peak to another. In such cases, resort must be had to the process of triangulation, which consists, in the simplest case of a single triangle, in measuring one side and the angles of the triangle and then deriving the other two sides by computation. The measured side of the triangle is called the base, and it is evident that the other two sides are fixed when the angles and this

base side are known. Similarly, when any such inaccessible side is known it may be made the base for a second triangle, and so on indefinitely, or throughout a series or chain of triangles, the single base line and the measured angles enabling us to calculate every line in the chain. Systems or chains of triangles of this sort are useful in determining the true relative positions of points along a river, about a lake, along the ocean coast, and, in general, wherever the intervening surface of the earth is inaccessible.

It is easily seen that the base line in a triangulation is an important line, since any error in it is multiplied as many times as it is contained in any computed side; and since the computed lines are often many times as long as the base, a small error in the latter may give rise to a large error in the former. This renders it essential, in many cases, to measure bases with a degree of care and refinement far surpassing the ordinary needs of the surveyor in defining the bounds of property interests. Especially is this so with bases in the extended chains of triangles used in geodetic work, one of the principal objects of which is the determination of the size and shape of the earth. Hence, it has happened that various devices have been contrived for the special purpose of securing precision in the measurement of base lines, and such devices are known under the general designation of base apparatus.

### TYPES OF BASE APPARATUS.

Of the earlier forms of base apparatus, chains, wooden rods, and glass rods are the most important. These, however, have been almost wholly supplanted by metallic bars, which are still in most common use. More recently the availability of long metallic tapes and wires has been recognized. These various forms of apparatus may be classified under three distinct types, namely: 1st, the chain and pin type; 2d, the single bar type; and 3d, the multiple bar type. The characteristics of these types may be briefly explained as follows:

(1) The chain and pin type is illustrated in the ordinary surveyor's chain, which is one of the best known and most useful forms of apparatus. Under the same head must be classed the long tapes and wires used recently in work of precision. To attain this precision, much greater care in manipulating is essential than in ordinary chain-

ing. The tape is suspended on specially prepared supports; it is stretched by a definite tension, and the positions of its ends are defined by marks on stable stakes or stands instead of by pins as in chaining.

Specimens of this first type are seen in the chains and tapes of the exhibit.

(2) The single bar type comprises all forms of apparatus which make use of but one measuring bar. Such bars are in general line-measure bars; *i. e.*, their lengths are defined by microscopic lines engraved on the polished upper surface, or on the neutral surface of the bar at its ends. One form of this type is seen in the Iced Bar Apparatus of the exhibit.

Since but one bar is used, and since such a bar is of necessity short compared with chains or tapes, it must be applied many times in the measure of a base. Hence, its successive positions must be marked with great care in refined work in order to prevent accumulation of error. This requirement is met by microscopes mounted on stable stands or posts. The microscopes are provided with micrometer wires, which are movable by means of a fine screw and visible along with the object observed. Thus the defining line at the end of the bar may be brought into coincidence with the micrometer wires, or the wires may be put in coincidence with the line when it is in focus under the microscope.

The measurement of a base with this kind of apparatus proceeds in essentially the same way as with a chain and pins, the bar taking the place of the chain and the microscopes the place of the pins.

(3) The multiple bar type comprises all forms of apparatus which use two or more bars simultaneously in measuring a base. Such bars may be end-measure bars (bars placed end to end in actual contact), or line-measure bars. In the latter case, some microscopic or equivalent device must be used to determine the relative positions of the ends of the bars. Examples of this type are seen in the Secondary Base Apparatus and the Duplex Apparatus of the exhibit. Both of these forms use end-measure bars.

In the measurement of a base these bars are placed end to end successively, each bar in turn defining the progress of the work until another is adjusted in front of it.

REQUISITES IN USE OF BASE APPARATUS.

The attainment of precision in the measurement of a base depends on certain essentials which must be secured in the use of any form of apparatus. These are: 1st, a knowledge of the length of the apparatus; 2d, a measure of its alignment or deviation from the direction of the base line, and 3d, a measure of the fractional distances which may appear at the ends of the base or at any intermediate points along it.

Of these requisites the first is by far the most important, and it is alone worthy of special remark here. The length of a bar depends chiefly on its temperature. Hence the temperature of the measuring bar or tape must be sought with all the precision attainable. Two methods of securing this end have been used. The first of these depends on the application of a thermometer, while the second seeks to keep the measuring bar at a constant temperature. Mercurial thermometers are used, for example, to get the temperature of the bars of the Secondary Apparatus. Two of them are placed alongside of and in contact with each bar. The Duplex Apparatus makes use of another form of thermometer, known as a metallic thermometer. In each tube of this apparatus there are two bars of nearly equal length, one of steel and one of brass. They are so arranged that the measurement may be conducted with and expressed in terms of either component. The difference between the measured lengths as expressed by the two components affords a measure of the average temperature of either component during the measure. To get the temperature of the long tapes both the mercurial and the metallic thermometers have been used, the latter being secured by the use of two tapes of different metals. The Iced Bar Apparatus, on the other hand, makes use of the method of controlling the bar's temperature, the controlling element being melting ice, with which the bar is completely surrounded when in use.

WASHINGTON, D. C.,
*May* 1, 1893.

# UNITED STATES COAST AND GEODETIC SURVEY.

**T. C. MENDENHALL, Superintendent**

# TRIANGULATION AND RECONNAISSANCE.

---

In any survey it is necessary to know the relative positions of some principal points of reference upon which to base the work. In other words, the distances and directions between certain points must be known.

When the area to be surveyed is small or unimportant, the distances may be measured directly upon the ground, with chain or tape, and the directions may be obtained by a compass or surveyor's transit. But when a survey is to cover an extensive territory, or when the greatest precision is desired, this method is unsatisfactory. Aside from the difficulties and delays experienced in making accurate linear measurements upon even moderately level ground, the natural conditions frequently render direct measurement impossible. Bays, rivers, mountains, and forests are some of the obstacles to such work.

To avoid these difficulties the method called *Triangulation* is employed. This may be defined as the process of dividing a portion of the earth's surface into a number of triangles of as large size as possi-

ble, these in turn being subdivided into smaller triangles, until enough points have been fixed to permit an accurate delineation of the features of the surface. This method rests upon the geometrical proposition that if one side and the angles of a triangle are known the remaining sides can be determined.

A single line, forming a side of one of the triangles, is measured with extreme care. The angles of the triangles are measured and the distances between the connected points are then computed, one from another, through the successive triangles, proceeding in regular order from the measured line or *base*.

From these fundamental ideas it is evident that the three stations forming each triangle must be intervisible. It is also desirable that the triangles should be as nearly equilateral as possible.

The work of selecting points which shall fulfill these conditions is called *Reconnaissance*, and is the most difficult and exacting task of an extensive survey. No two regions call for the same treatment, but some general considerations can here be briefly outlined.

A reconnaissance may be preliminary to minor triangulation along the seacoast, a river, or an estuary, where the general dimensions of the triangulation will be fixed by the natural conditions, and the range of selection of points will be correspondingly limited. Or again, it may have to do with the arrangement of a great triangulation to cover a wide region.

Careful study will then be required in order that the resulting project may best satisfy all the conditions. Hence, for triangulation of the largest size, the reconnaissance is a matter of great complexity and demands great skill, experience, and judgment. Heavily wooded country is the most troublesome, and makes it necessary to climb the tallest trees, or to raise poles taller than the trees, from which the distant horizon can be seen and such observations made as may be practicable.

When the reconnaissance of a region has been completed and the stations of the triangulation have been selected, the three angles of each triangle are carefully measured.

Instruments of various sizes and stands or piers of different kinds are employed, according to the character of the country, the size of the triangulation, and the facilities at hand.

These conditions also determine the kind of signals or sighting marks used at the distant stations.

For triangulation of great size, with lines of from one to two hundred miles long, wooden supports for the instrument are unsatisfactory. Brick, stone, or cement are much safer materials.

At such distances the only marks which can be seen are heliotropes by day and powerful lamps by night. The heliotrope is a small mirror so arranged that it reflects the sunlight towards the observer.

The theodolites used are direction instruments with well graduated circles from twelve to twenty-four inches in diameter. The circle is read to a second of arc or closer, by three or four micrometer microscopes, the mean of the readings constituting one observation of a direction. The precision of pointing on the distant signal is sometimes increased by using an eyepiece micrometer, the mean of several pointings being combined with the mean reading of the circle. Were all the conditions perfect, a single careful observation of each direction would be sufficient. But the most excellent instruments have some defects; the most careful observers are liable to some slight error; and above all, the line of sight, passing through miles of atmosphere of variable density and temperature, is subject to influences which defy analysis, and which can be neutralized only by making many observations on different days and under different conditions. In order also to eliminate errors due to irregular graduation, these successive observations are made on different parts of the circle by shifting it through a definite portion of the circumference after each set of observations. The number of such "positions" may vary from seventeen to sixty-one for primary triangulation. From one to three series may be observed in each position, giving from forty to sixty-five measures of each direction. The average probable error of a direction should not exceed $0''\cdot1$.

Triangulation of such extent is possible only in regions of high mountains, where the curvature of the earth is overcome by the natural elevations. In lower country, heavily wooded, or where mountains of nearly uniform height are closely crowded together, triangulation must have more moderate dimensions, with lines from ten to forty miles long. In such country it will often be necessary to elevate the instrument from twenty to one hundred and fifty feet

above the surface, either on some existing building, or upon a timber structure built for the purpose. Heliotropes and lamps will still be used, but signal poles are also useful in cloudy weather.

The instruments and methods of work are similar to those described above, but a somewhat smaller number of observations will generally suffice.

In secondary and tertiary triangulation, the lines may range downward from twenty miles to less than one mile. The same general principles apply, but the details of the work will vary with the circumstances. Heliotropes are rarely used, and the angles are often measured with repeating theodolites, from six to twelve inches in diameter. The principal angles require from one to six sets of twelve repetitions each, while for minor points a single set of three or six repetitions is sufficient. After measuring the angles, the triangle sides are computed. The latitudes and longitudes of all stations are also computed, by geodetic formulæ, from the standard points astronomically determined.

The accuracy attained in triangulation may be tested in various ways. The sum of the angles of a plane triangle must equal 180° and the same condition holds good in a geodetic triangle, after reducing it to a plane triangle by deducting the "spherical excess" due to the figure of the earth. The difference, if any, between 180° and this corrected sum is the "error of closure", which in the best work will average rather less than 1″. We may also test a triangulation by comparing the computed length of a line obtained through a long chain of triangles with an actual measurement of the same line. In the triangulation between the Maryland and Georgia base lines, six hundred and two miles apart, the discrepancy was scarcely perceptible, being little over half an inch in a thirty-mile line. Equally small discrepancies have been found in other triangulations, and the method may be considered practically exact.

WASHINGTON, D. C.,
*May* 1, 1893.

# UNITED STATES COAST AND GEODETIC SURVEY.

**T. C. MENDENHALL, Superintendent.**

# TIME, LATITUDE, AND LONGITUDE.

*Definitions.*—Meridian: A plane passing through the vertical and parallel to the axis of rotation.

Latitude: The angle between the horizontal plane and the axis of rotation.

Longitude: The angle (degrees or hours) between the meridian and the prime meridian.

Longitude is reckoned east or west from any given meridian called the Prime Meridian. Latitude is reckoned north or south from the equator. Latitude and longitude are coördinates that fix the position of points on the earth's surface.

## TIME.

Several kinds of time are used by astronomers: mean solar time; true or apparent time, and sidereal time.

Solar time is measured by the daily motion of the sun; the interval between two successive upper transits of the sun over the same meridian is a solar day, which is divided into 24 hours, and the hour angle of the sun at any instant is called solar time. But the solar days are of unequal length, owing to the obliquity of the ecliptic and the variable motion of the earth in its annual orbit, hence it would be difficult

to regulate clocks to follow the real sun, and, in order to secure uniform time, a mean sun, that is the mean of the daily motions of the sun for the entire year, is supposed to move in the equator with uniform velocity. This mean sun measures mean solar time; it is sometimes ahead of and sometimes behind the real sun, but never differs from it more than about 16 minutes. Clocks in general use and navigators' chronometers are regulated to this time.

True, or apparent solar time, is measured by the real sun, and the difference from mean time is called the equation of time.

Sidereal time is measured by the stars, or rather, by the daily motion of that point in the equator from which the true right ascension of the stars is reckoned, called the vernal equinox. Two successive upper transits of the vernal equinox over the same meridian determine a sidereal day, which is nearly 3m. 56s. shorter than a mean solar day, but divided, like it, into 24 hours. About March 21 the sidereal and mean times agree; the former gains on the latter an entire day in a year.

The Civil Day commences at midnight, and is divided into two periods of 12 hours each; the first is marked a. m. and the second p. m.

The Astronomical Day commences at noon on the civil day of the same date, or 12 hours later than the civil day, and the hours are counted from 0 to 24.

The Sidereal Day commences at the instant the vernal equinox makes its upper transit, and, therefore, changes in twelve months through the entire 24 hours. The hours are counted from 0 to 24.

*Time determination.*—Time may be determined by observations on the sun or stars with a sextant, an altazimuth for rough purposes, or with a transit adjusted to the meridian, for refined work. With the last instrument a chronograph is frequently used for recording the observations. The telescope usually has from five to eleven equidistant lines ruled on glass (or spider lines), which are placed in the common focus of the eye piece and object glass, the center line being adjusted to the optical axis of the telescope and set in the meridian. When ready for observations, the observer sets the telescope at the proper angle to observe the passage of the star across the meridian, and records on the chronograph the transits over each line by inter-

rupting the circuit with an observing key held in the hand and electrically connected with the chronograph, on which a break-circuit chronometer is making a continuous record. The chronograph sheet is read by means of a glass scale.

LONGITUDE.

Longitude may be determined by observing the eclipses of Jupiter's satellites, by solar eclipses, by moon culminations, occultations of stars, by transporting chronometers, etc., but the most accurate and generally adopted method is the comparison of the local time of a place of which the longitude is to be determined, with the local time of a place already known, by means of the electric telegraph. The difference of longitude of two points is the time it takes a celestial body to pass from the meridian of one to that of the other, or the difference in the local times of the two meridians. Instead of depending on the passage of one star over the meridians, about twenty stars are observed at each station on several nights to determine the local times. Each station is supplied with a transit, a break-circuit chronometer, a chronograph, and a set of telegraph instruments. Two time-sets are observed at both stations each night, and between the observations the two chronometers are compared over the telegraph line by means of chronometer signals or arbitrary breaks, made by the observers alternately, and recorded on both chronographs. The comparison of chronometers only requires about three minutes. The transmission-time of the electric current is derived by sending signals in both directions, and the personal equation of the observers, by interchange of stations after half the number of nights' work has been obtained, or by direct observations, if the work is not a primary determination.

LATITUDE.

The latitude of the place is equal to the altitude of the pole, or the declination of the zenith at that place.

Rude determinations of latitude may be made by sextant or altazimuth instruments on the sun or stars, but refined determinations are usually made by observations on the stars with a zenith telescope. The principle on which this instrument depends is the measurement, with a micrometer, of small differences of zenith distance of two

stars, nearly equidistant from, but on opposite sides of the zenith. These two stars, forming "a pair," should culminate within from one to twenty minutes of each other, and they are bisected by the movable micrometer line as they reach the meridian. The telescope is set to the mean zenith distance of the two stars, one of which passes above, and the other below the center of the field.

From fifteen to twenty-five pairs should be observed on three nights for a good determination.

INSTRUMENTS.

The following instruments in the Exhibit are used in astronomical observations:

A 46-inch (117 cm.) transit, improved at the office.
A 37-inch (94 cm.) transit, made at the office.
A cylinder chronograph, Fauth & Co.
A set of telegraph instruments.
A break-circuit chronometer.
A prismatic transit.
A 46-inch (117 cm.) zenith telescope.
A 26-inch (66 cm.) zenith telescope.
A 31-inch (79 cm.) meridian telescope.
A altazimuth instrument, Repsold.
A sextant and artificial horizon.

---

For fuller details, refer to Chauvenet's Spherical and Practical Astronomy, or to the Report of the U. S. C. and G. Survey, 1880, Appendix No. 14.

WASHINGTON, D. C.,
*May 1, 1893.*

# UNITED STATES COAST AND GEODETIC SURVEY.

**T. C. MENDENHALL, Superintendent.**

## GRAVITY.

---

The measurement of the force of gravity is effected by means of a pendulum. Other means have been employed, but the pendulum furnishes the most precise as well as the most convenient way. Ever since Bouguer made his famous experiment at Quito, 150 years ago, where a simple piece of brass was suspended by a thread of the aloe, the form of the instrument has undergone successive improvements until we now have a modern type which is compact, very portable, and of the highest degree of precision.

In passing let it be remarked that the first experimental proof of the flattening of the earth at the poles was obtained by counting the oscillations of a pendulum in different latitudes, and that this instrument still holds its supremacy as the best method of determining this important quantity. Not only do the observations accord well with one another, but the results by other methods are coming more and more towards the form set by the pendulum.

Every nation of importance has made gravity work the subject of study, and different shapes have been given to the instrument accord-

ing to the object in view and the degree of precision expected. Leaving, to one side the earlier experiments, the most prominent types are the invariable pendulums used by the English, French, and Russians for measuring differences in the force of gravity and the reversible ones used by the Germans for absolute determinations. The short forms, which have as yet only been employed for relative work, have recently been adopted by the Coast and Geodetic Survey and have also been employed by the Austrians.

A brief statement will now be made of the characteristics of the different types exhibited at the present time.

The Repsold reversible pendulum is designed to measure the absolute force of gravity and at the same time may be used differentially. It is made of brass and consists of a hollow tube supporting a bob at each end. The distance between the two points of suspension is one metre, and the distribution of matter in the instrument is such that the time of oscillation is the same whether the pendulum is supported at one end or at the other. The supporting parts consist of a steel plane upon which the instrument rests, and a beveled piece, also of steel, firmly attached to the pendulum. These beveled pieces are called the "knives," and are, of course, similar in construction for both ends. Indeed, they are so made that they may be used interchangeably, and thus eliminate sources of error. The external form of the pendulum is perfectly symmetrical with reference to the center of figure, so that the resistance offered by the air is the same for either position. This is one of the strong points of this form of instrument, as the atmospheric correction is a very important quantity, and one that has given considerable trouble in dealing with absolute measures of gravity. The most prominent defect of the Repsold apparatus is that the tripod is weak and is set into vibration by the movement of the pendulum; moreover, the shape of the latter is such that the air resistance, although the same for both positions, is too great. The accuracy of the determination of the time of one oscillation depends partly on the length of time that the pendulum will swing before coming to rest, and in this respect Repsold's pendulum attains a precision less than half that given by other forms. Part of this apparatus consists of a comparator used in getting the distance between knives in terms of a metre supported ver-

tically near by. To calculate the absolute force of gravity it is of course necessary to know this distance, and it must be determined with an accuracy equal to that attained in the determination of the time of oscillation of the pendulum.

The Repsold pendulum was supplanted in the Coast and Geodetic Survey practice by another pattern, due to Professor C. S. Peirce. This instrument was also intended for absolute measures, but embodied several improvements on the Repsold type. As in the Repsold, the material was brass and the stem was a hollow cylinder, but the external form was less complicated and its greater weight and freedom from irregularities enabled it to swing four or five hours before coming to rest. Two lengths of this instrument were made; one in which the distance between the knives was a metre and the other in which it was a yard. This supplied a new method of comparing the length of a metre with that of a yard through a comparison of the times of oscillation of the two pendulums, and a subsequent comparison of the length of the pendulums with the respective standards.

The stand on which the Peirce pendulums were swung was much more stable than the Repsold one, and the correction due to the flexure of the support was thereby reduced considerably; but in all the forms alluded to above, the flexure and oscillation of the support, due to the motion of the pendulum, has always been a source of discrepancy in the comparison of results obtained by employing different forms of apparatus.

In 1890 a complete departure was made in the Survey regarding the form of instrument and the method of observation. A small pendulum, one-fourth of the length of the previous ones, was constructed as designed by Dr. Mendenhall, and an elegant method of making the observations, also suggested by him, permits the work to be done with ease and accuracy. As previously stated these instruments have as yet only been employed for relative determinations, but that they may be used as reversible ones and thus give absolute values for gravity, there seems no reasonable doubt.

The metal used is a composition of copper and aluminum. The form is that of a flat stem supporting a lenticular bob. The supporting parts are of agate; in one form the beveled piece above attached to the pendulum rests on a plane; in another, the plane is attached to

the pendulum and rests on the beveled piece below. The pendulum swings in a brass chamber from which the air can be exhausted to any pressure desired. The observations are made by noting the time when there is a coincidence between the beat of the pendulum and that of a chronometer, and the observation of two such coincidences enables us to deduce the period of the pendulum in terms of that of the chronometer. The pendulum is so made that its period is nearly but not quite equal to a half second, so that a coincidence occurs every five or six minutes. By an ingenious mechanical device a beam of light is thrown every second into the pendulum receiver, and there falls upon two mirrors, one being on the pendulum and the other permanently fixed by its side. When the pendulum is hanging vertically, the two illuminated slits, as seen through the observing telescope, coincide, but in any other position of the pendulum only the one reflected from the fixed mirror is seen; that from the pendulum mirror being thrown up or down, according as the pendulum is on one side or the other of its equilibrium point. When the pendulum from continued swinging has lost or gained a whole vibration on the chronometer, a recurrence of the coincidence takes place and is observed as before. The advantages of this new apparatus are numerous, the support is entirely free from flexure, the swinging is done in a closed chamber protected from currents of air and rapid changes of temperature, the observations are easily made, the pendulums are very portable, and the accuracy attained is far superior to any hitherto reached.

*Consult:* Volume VII., Mem. Royal Astronomical Society.
Sabine, Pendulum Experiments.
Great Trigonometrical Survey of India, Vol. V.
Clarke's Geodesy.
Bessel's Pendeluntersuchungen.
Reports Coast and Geodetic Survey.

WASHINGTON, D. C.,
*May* 1, 1893.

# UNITED STATES COAST AND GEODETIC SURVEY.

T. C. MENDENHALL, Superintendent.

## TOPOGRAPHY.

Topography, as the term implies, is the typical description or representation, by conventional signs and symbols, of the features of the surface of the earth.

The science and art of topographical surveying and the production of a map from its results, is the process and means by which these signs and symbols are made to correspond, in relative position and configuration, to the features of the earth they are intended to represent.

Topography and topographical surveys have been variously defined. By some their significance has been limited to undulations and accidents of ground and occuring incidents of water. Others have added features of natural growth and the character of ground, such as forests and copse, prairies, desert and arid lands. Others, again, including features of culture and the artificial structures of mankind. The latter type is the most comprehensive and useful picture of the terrene.

The enterprises of the day call for reliable information on all practical subjects, and topographical surveys and maps that do not

meet these public requirements fail in supplying a demand becoming more and more essential in the economy of modern improvements.

In devising a project for a topographical survey, the primary consideration should be the purpose it is intended to subserve; given the purpose, and the next important consideration—that of the scale of the survey—is logically suggested, and relatively its cost.

Special surveys, intended as the bases for constructive works occupy the first rank, both in the measure of accuracy and expensiveness. They should be on such a scale and of such character in given data as to fully meet the purposes required. But these are in such variety that no adequate rule can be given for them here.

A topographical survey, however, under a proper system of operations, can be so made as to form the basis of first-class map construction, which shall meet most purposes of general public utility; such as the preliminary location of railroads and highways; the study of water supply and drainage; the relations of land to water in connection with navigation; for military movements and defense; in cadastral detail for taxation; for general engineering projects and like purposes.

In such a survey the question of scale becomes a most important one in the economy of the work. In its practical operations material objects and definite natural features can be more readily and accurately determined than what may be called the vertical measurements of the survey; for the obvious reason that the first mentioned are visible objects which can be observed upon, while the representations of "relief" by contour curves—the preferred symbol of illustration—are imaginary and indefinite lines; unless, as in special cases, the contour lines are "run out" by actual level stations. For such work the scale should not be so small as to embarrass the topographer by too much minutiæ in representation, nor so large as to affect the accuracy of his judgment of distance, proportion and configuration of details that may not require special measurement.

The methods of operation and the choice of suitable instruments are also essential factors in the successful execution of a topographical survey.

Each subject of topography should be treated according to the character of the given locality, and to each assigned its appropriate scale and method of execution. In a country of varied configuration

and largely diversified detail, so full as to justify all the care and refinement possible with the larger scales, there may occur tracts of marsh, sandy waste, or woodland barren of topographical detail. Uniformity requires a given scale, as a unit, to the whole survey. It is manifestly better, therefore, to apply the larger scale to the simpler topography than to jeopardize the elaboration of the more complex features by using an inferior scale.

Various methods of operation and various instruments may, of course, be used in making a topographical survey; provided always that the result is up to the required standard.

The instrument found, in the large experience of the Coast and Geodetic Survey, to be the most comprehensive and effective, is the plane table; and the best system to be followed in its use, is that of graphical triangulation.

The plane table is one of the oldest surveying instruments, its history dating back to 1537. It was introduced into the Coast Survey by Mr. Hassler, the first Superintendent, and has been much developed and improved in the evolution of that work. As now used by the expert topographers of the Survey, it is an instrument of great scope and power. For first-class topographical work it should have firmness and stability.

No other government organization has carried forward so thorough and accurate a system of surveys over so large a section of the earth's surface and comprehending such varied and diverse typical features as those embraced within the belt of topography which borders the coasts of the United States.

This system of surveys reaches from Etang Harbor, Province of New Brunswick (latitude 45° 03′ longitude 66° 47′), to the Pribilof Islands, Alaska (latitude 57° 10′ longitude 170° 20′), being sixty-one degrees of a great circle, equal to 4 224 statute miles.

The most northern point is Camp Colonna, Alaska (latitude 67° 23′ longitude 141° 00′); the most southern point is Key West, Florida (latitude 24° 30′ longitude 81° 50′); the distance between these points is 3 835 statute miles.

The extent of general coast line is on the Atlantic 3 895 miles; on the Pacific 1 810 miles; in Alaska 4 750 miles.*

* These measurements are for the continental coast line only; that is, a line following the general trend of the coast, making no note of minor irregularities, and stretching straight across openings of but 10 miles in width.

The actual or developed coast line would include all islands, bays, sounds, and rivers in the littoral or tidal belt.

For Alaska the actual shore line would have a length of about 26 364 miles, taking in the Aleutian Islands, and the bays, inlets, islands, etc., from Dixon Entrance to Point Barrow.

The area in square miles covered by the Survey is on the Atlantic 28 950; on the Pacific, 5 280. In Alaska 720; of resurveys 2 450; making a total of 37 400 square miles.

The belt of topography on the Atlantic has averaged about 7·4 square miles per linear mile of general coast line.

This work is contained on 2 240 original sheets. The scale applied to the detailed topography has been generally that of $\frac{1}{10000}$, with occasional large scales for harbor and special surveys. On the Southern Atlantic coast, and for simple topography of small relief, the scale of $\frac{1}{20000}$ has been adopted.

Some expert work has been done on the coast of California on the scale of $\frac{1}{40000}$.

Topography comprises so much of art that the question of personality enters largely in the facility of expressing it, and topographical surveys involve such varied processes, that it is difficult to make hard and fast rules to govern them. It certainly requires a high order of artistic skill and intuition. It has been said by one of the most distinguished scientists of our own country, "that while but little more could be done to perfect the principles of other departments of mathematical science, topography was still susceptible of development and improvement." Certain it is, that each topographical proposition presents a problem as varied and often as difficult of solution as the phases of nature with which it has to deal.

WASHINGTON, D. C.,

*May* 1, 1893.

# UNITED STATES COAST AND GEODETIC SURVEY.

**T. C. MENDENHALL, Superintendent.**

## HYPSOMETRY.

---

Hypsometry (Gr. ὕψος, height, and μέτρον, measure) is that branch of science which treats of the determination of absolute or relative elevations or heights. The mean sea level is the usual plane of reference from which heights are determined, but frequently other arbitrary planes are used for special purposes.

Three principal methods are now in use for measurement of elevations, according to the degree of precision desired. These are: First, by spirit leveling; second, by vertical angles; and third, by the use of the barometer.

The first method is the most precise and is accomplished by means of an instrument called a level, which consists essentially of a telescope suitably mounted on a portable tripod stand, and carrying or having attached, as the case may be, a delicate spirit level, so that it may be quickly and readily placed in a truly horizontal position. Graduated rods are then held at two points, the instrument usually being placed midway between them. The telescope is sighted first

column of mercury will fall, owing to the diminution of atmospheric pressure. If other conditions, as temperature, etc., remain unchanged we would, from the amount of this fall, at once have the means of computing the height, but as the other conditions are not constant we must correct for temperature, for the change of the force of gravity due to elevation, and for the change of gravity due to change of latitude.

Both mercurial and aneroid barometers are used in hypsometric measures, the former giving the most satisfactory results, but the latter being often preferred on account of their greater convenience and portability. The aneroids are chiefly used, however, as differential instruments.

For further information on the subject of barometric measures see Dr. A. Guyot's Meteorological and Physical Tables, and Appendix No. 11 of U. S. Coast and Geodetic Survey Report for 1871.

A fourth method, depending upon the variation of the boiling point of water with variation of atmospheric pressure has been practically abandoned, as its results were frequently very inaccurate; but owing to recent progress in precise thermometry, largely the outcome of the labors of the International Bureau of Weights and Measures, it now promises to furnish results of fair accuracy.

WASHINGTON, D. C.,

*May 1st, 1893.*

# UNITED STATES COAST AND GEODETIC SURVEY.

**T. C. MENDENHALL, Superintendent.**

## HYDROGRAPHY.

---

Under this head are embraced all operations of the Coast and Geodetic Survey which are carried on upon the waters, either of the ocean or navigable rivers. One of the principal objects of the Survey is, and has been, for a period of half a century, to furnish good and reliable charts of the coasts of the United States, and of its harbors and navigable rivers. These require in their construction a combination of skillful labor, differing greatly in means, appliances, and methods.

First in order is the reconnaissance and triangulation. The instruments used in these operations are described under the heads of geodesy and astronomy. Next comes the topographical survey of all that portion of the earth's surface which lies above the water. It includes all accidents of ground, all natural or artificial developments of surface, and everything useful for purposes of commerce and defence. The means used are described under the head of topography.

Third in the chronological order of conducting a survey, but equal in its usefulness, is the development upon the chart of all that portion of the earth's surface which lies beneath the water. Most of

this important work is carried on by officers and enlisted men of the Navy of the United States detailed for service in the Coast and Geodetic Survey for a series of years. There are 37 officers and 250 petty officers and seamen now engaged upon this duty.

The steamer *Blake*, one of the vessels engaged in this work, is represented by a model in the Coast Survey exhibit, and the vessel herself, completely fitted for all kinds of hydrographic work, is on exhibition at the water front of the Exposition.

In the chart room of the *Blake* may be seen a projection or hydrographic sheet as furnished from the Coast Survey Office, showing the shore line, and triangulation points represented thus $\triangle$. These points having been determined by the geodetic branch of the Survey their positions are known absolutely. The centers of these little triangles correspond in position to certain land marks on or just beneath the surface of the earth, the descriptions of which readily enable the field party detailed from the ship to recover them. Once found they are used as signals and as points from which to "cut in" other signals. The latter may be objects in the landscape, such as a church spire, a house chimney, a peculiarly shaped rock or tree, or, if such are wanting, signals must be built in some one of the forms shown by the models on exhibition.

A sufficient number of signals having been built and cut in by theodolite angles, and a tide gauge set up, the next step is to run the lines of soundings. Having decided where the first line is to begin, the ship or boat is moved to that point. The observers with sextant in hand, the recorder with a watch and sounding book, and the leadsman take their respective positions; the officer in charge directs the recorder to make a note, say, as follows: "Line begins at angle one ($\sqrt{}$), twenty metres from shore, course about east;" the observers read from the sextants the angles observed, the leadsman gets a cast of the lead and reports the number of feet or fathoms, and the recorder notes the time, all of which is duly entered in the record, and the ship or boat starts ahead. Thereafter angles are taken as often as necessary, each pair locating the position of the boat at that instant of time, until the line is ended, when a final pair is taken and the boat moved to a position at the beginning of a new line. Soundings are taken as often as possible, but preferably at

equal intervals of time. When practicable the lines of soundings should be run on range, that is with two objects on shore, and the boat on the same straight line.

Mention has been made of the tide gauge. While the boat has been running its lines of soundings the water in all probability has not maintained the same level; but by means of the tide gauge, if we note the height of the water with reference to a zero mark on the staff at short intervals, we can reduce the soundings so that they shall represent the depth of the bottom below the zero mark, or any other level. The level or "plane of reference," as it is called, adopted by the Coast Survey is that of mean low water. Now, if on the staff the heights of all the low waters that occur during a lunar month be noted, their mean (for ports on the Atlantic and Gulf coasts) will be the plane of mean low water, referred to the zero mark; and as we already have a record of the height of the water noted at ten-minute intervals on every day soundings were made, all the soundings can be reduced to this plane, which is what is actually done. Again, if a permanent mark be made on shore at so many feet and inches above or below the zero mark, we can at all times refer the plane of reference to the permanent mark and thus, in subsequent surveys, dispense with observations for its redetermination.

Such marks are to be found in nearly every port on the coast of the United States and are known as "bench marks."

The Coast Survey Office exacts that in smooth water the reduced soundings on lines crossing each other shall not differ more than two-tenths of a foot for soundings under fifteen feet, and not more than two feet for soundings of one hundred feet.

At the end of each day's boat or ship work the results are graphically transferred to what is known as the progress sheet. With the day's record at hand, every position of the boat corresponding to any two angles made on any three points on shore, is plotted by means of a protractor. It will be noted that the practice of plotting is merely a graphic solution of the three-point problem.

The successive positions of the boat being plotted, and the interval between soundings, and also the number of soundings being shown on the record, it becomes an easy matter accurately to space the soundings. The result is practically as though the boat's position had been determined for each sounding.

Because of the accuracy demanded of the hydrographer, even in water so deep that no possible danger can ensue to the largest ship afloat, it must be evident that the mariner's chart has a twofold object: first, to indicate to the navigator the hidden perils which he must avoid, and, second, to display the configuration of the bottom so truly that, by the use of the lead, he may fix his position relative to those perils or, when off shore, determine his distance from land.

For details of the theory and practice of hydrographic surveying the inquirer is referred to:

U. S. Coast and Geodetic Survey Reports.

General Instructions for Hydrographic Work, U. S. Coast and Geodetic Survey, 1883.

Chauvenet's Astronomy.

Jeffers's Surveying.

Howell's Marine Surveying.

WASHINGTON, D. C.,
*May* 1, 1893.

# UNITED STATES COAST AND GEODETIC SURVEY.

**T. C. MENDENHALL, Superintendent.**

## TIDES AND CURRENTS.

By the observation and study of tides and currents the Coast and Geodetic Survey is enabled to modify the depths given by the lead and line during the progress of its hydrographic surveys, and place upon its charts of the coast the depth at mean low water; to give on the same charts simple means for finding the time and height of the tide, and the direction and strength of the tidal currents; to publish, in advance, tables of the times and heights of every high and every low water at more than a thousand ports and stations on the coast of North America; to furnish data for engineering purposes along tidal waters; to detect upheaval or subsidence of the coast; to aid in determining the motion of the earth's rotation axis relatively to the geographic poles, the moon's mass, and the history of the earth and moon as two closely related bodies of the solar system. This department of the survey work is represented by a self-registering tide gauge, a tide-predicting machine, five current meters, and the instruments employed in collecting specimens of water and determining their relative densities.

### THE SELF-REGISTERING TIDE GAUGE.

The rise and fall of the tide may be obtained roughly by inspecting the shore, or any fixed body (as a wall) rising out of the sea; or, more

accurately, by reading the height of the sea upon a tide staff divided to feet and inches (say) and fixed in a vertical position; or by means of a tide staff supplemented by a self-registering tide gauge. Several forms of the latter instrument are used in the Survey; the one exhibited is the Stierle gauge improved at the Survey Office. The float rises and falls with the tide in a vertical tube or box to which the water is admitted by a small opening below low water; and its motion, which is not materially affected by wind waves, is transmitted, reduced in any desired ratio, by simple mechanism, to a pencil resting upon a long sheet of white paper carried by clockwork transversely to the motion of the pencil. The result is an undulatory trace on the paper, representing the rise and fall of the tide. The record is completed by occasionally noting on the trace the correct time, and the corresponding reading of the tide staff. This instrument is simply a device for obtaining the height of the tide on the tide staff at any hour without the constant attendance of an observer. A miniature tide gauge of a slightly different pattern and a tide indicator in miniature are in operation and will be explained by the officer in charge of the exhibit.

#### THE TIDE-PREDICTING MACHINE.

This tide-predicting machine is the invention of the late Prof. William Ferrel while engaged on the survey, and is used in the preparation of the annual tide tables for the coasts of the United States. When set for a particular port and year, which can be effected by one person in half an hour, the operator seats himself before the machine, turns the crank with the left hand, and with the right tabulates for the printer the times of high and low water read from the dial, and the heights read from the scales on the left; doing as much work in one day as he could do without the machine in forty.

### CURRENT METERS.

#### PILLSBURY'S DEEP-SEA CURRENT METER.

This instrument was devised by Lieut. J. E. Pillsbury, U. S. N., Assistant Coast and Geodetic Survey, for obtaining the *velocity* and *direction* of ocean currents at great depths. A detailed description

of the instrument and the method of using it is given in appendix No. 14, of the Annual Report of the Coast and Geodetic Survey for 1885.*

In brief, the velocity part of the instrument consists of a freely moving rudder of thin metal, to the front edge of which is attached a wheel made of four cones placed at the extremities of four spokes. When the instrument is in the water the rudder immediately takes the direction of the current, forcing the wheel into position where the current causes it to revolve. The revolutions are counted by the differential wheels connected to its axis, and the number recorded in a given time determines the velocity.

The direction part of the instrument consists of a compass swung in gimbals at the lower extremity of the instrument. The magnetic needle of this compass being free to assume the magnetic meridian, and the rudder above described free to assume the direction of the current, the angle between the two gives the direction of the current. A simple device consisting of the fins attached to the rudder, the circular rack and the little propeller wheel at the top of the instrument serves to lock the needle and the rudder in the position they occupy at the instant of suddenly starting to raise the meter, thus preserving the direction of the current, which is read off along with the revolutions of the velocity wheel on the meters reaching the surface.

### THE DIRECTION-CURRENT METER.

This instrument† is a recent joint invention by Mr. E. S. Ritchie and Mr. E. E. Haskell, Assistant Coast and Geodetic Survey. As its name implies, it is an instrument for determining the *direction* and the *velocity* of a current of running water. It records these electrically on registers before the observer, so that when once in the water it only needs to be shifted from depth to depth at which information is required.

In observing a current the meter is suspended in the water by a single cable from a boat at anchor. The core of this cable is made up of the necessary number of insulated wires to form the operating circuits, while the armor or covering of it furnishes the necessary tensile strength for carrying the weight of the meter and the strain brought by the friction of the running water of both meter and cable.

---

* Also in Lieut. Pillsbury's paper on Gulf Stream Investigations and Results, Appendix No. 10, 1890.

† See Appendix No. 10, 1891, Part II.

The velocity wheel is of the propeller or screw type, conical in front to constitute a self-clearing prow for all debris moving with the current. The electric connection or the "make" of the circuit for transmitting the number of revolutions of the wheel to the counting register in the boat, is placed inside the meter where it is free from accident.

The central chamber or body of the meter is a compass, whose needle is free to assume the magnetic meridian at all times. This chamber is filled with oil, giving stability to and preventing rust of the needle and other mechanism. By the use of an electric circuit, the angle to the nearest degree between the direction of the current and the magnetic needle or meridian is transmitted to the *repeater* or direction register in the boat. The two observations, or the *velocity* and the *direction* of the current, can thus be taken simultaneously.

In connection with this part of the exhibit are also shown the hydrometer, hydrometer cup, and hydrophone, used by the Survey in the collection of specimens of water and in determining the relative density thereof.

---

## WORKS OF REFERENCE.

TIDES: Laplace, Mécanique Céleste; Airy, Tides and Waves; Ferrel, Tidal Researches; Encyc. Brit. 9th ed., article "Tides"; Admiralty Tide Tables; Tide Tables for the Atlantic Coast of the United States; Tide Tables for the Pacific Coast of the United States.

TIDE PREDICTING MACHINES: Proc. Inst. Civ. Engrs. (London), vol. 65; Appendix 10, U. S. Coast and Geodetic Survey Report for 1883.

CURRENTS AND HYDROMETRY: Francis, The Lowell Hydraulic Experiments; Révy, Hydraulics of Great Rivers; Harcourt, Rivers and Canals; Stevenson, Canal and River Engineering; Ganguillet and Kutter, Flow of Water in Rivers and Other Channels (translation by Herring and Trautwine); A. R. Harlacher, Die Messungen in der Elbe und Donau, etc.; K. R. Bornemann, Hydrometrie.

WASHINGTON, D. C.,
*May* 1, 1893.

# UNITED STATES COAST AND GEODETIC SURVEY.

**T. C. MENDENHALL, Superintendent.**

## DESCRIPTION OF THE C. AND G. SURVEY STEAMER "BLAKE" AND HER DEEP-SEA APPARATUS.

---

The *Blake* is a wooden schooner-rigged steamer of 540 tons displacement, with a mean draught of 9 feet 6 inches. The length on the water line is 148 feet; the greatest beam is 26½ feet. The engines are of the compound type and are capable of developing 250 horse power, which gives the vessel a speed of 9 knots [sea miles] per hour. Under ordinary circumstances she will maintain a speed of 8 knots per hour on a consumption of 4¼ tons of coal per day. The coal bunkers have a capacity of 120 tons.

The upper deck is flush and affords ample room for all the necessary deep-sea apparatus and machinery. The after part of the main deck is taken up by the living quarters of the officers. Amidships and forward of the wardroom bulkhead, on the same deck, are the engine room, drum room, galley, pantry, chart room, and petty officers' rooms, in the order named. The rest of the deck furnishes comfortable living and sleeping quarters for the greater part of the crew.

The lower or berth deck provides messing and berthing quarters for those of the crew not accommodated on the main deck. The complement of the ship is 8 officers and 35 men.

The *Blake* was launched in Baltimore, Md., in 1874, having been specially constructed so as to be able to keep at sea under all conditions of weather, as she was designed for deep-sea work. For this work she is probably equipped with the most complete outfit of any vessel in the world.

She is generally employed in what is called deep-sea or off-shore work. This term embraces deep-sea sounding, serial temperature, density, and current observations.

Her sounding work has extended over the entire Gulf of Mexico, a part of the Caribbean Sea and along the Atlantic coast of the United States. By means of the observations taken by the officers of this vessel a number of new and novel features connected with the Gulf Stream have been demonstrated; any one interested in this remarkable movement of the ocean will find a very interesting account of it in "Gulf Stream Investigations and Results," by Lieut. J. E. Pillsbury, U. S. N., published by the U. S. Coast and Geodetic Survey (Appendix No. 10, Annual Report for 1890).

The sounding machine is on the port side forward [the left-hand side looking towards the bow], where will also be seen the Sigsbee sounding rod, the sinker, the piano wire used as a sounding line, and specimens of bottom brought back by the rod.

By means of the Sigsbee machine the *Blake* has sounded in depths of over 4 500 fathoms. The "hand lead" on the starboard side is used in sounding in depths not exceeding 15 fathoms; the deep-sea lead rigged on the port side, in depths of from 15 to 60 fathoms; the Bassnett rod can be used for any depth from 1 to 100 fathoms.

The sounding machine is also used, in connection with the Negretti-Zambra thermometer, to determine the temperature of the ocean at different depths, and by means of water bottles to secure specimens of the water at these depths; these specimens are then subjected to analysis for density and examined for microscopic forms of marine life.

The water cup and sounding rod can be more carefully studied from the sections in the chart room.

Since 1885 the *Blake* has been chiefly engaged in investigating the currents of the Gulf Stream. This has been done by anchoring the vessel to the bottom by means of a small anchor [350 to 500 pounds] and a wire cable, and then noting by a device, either mechanical or electric, the actual velocity and the magnetic direction of the flow of water past the stationary ship. The two instruments in use for this purpose are known as the Pillsbury and the Haskell current meters; the former will be found in position ready for lowering from the Sigsbee machine, the latter on the other side of the deck near the mainmast. The anchor of the kind commonly used in this work is suspended from the boom projecting from the bows of the ship, and the wire attached to it leads to the reel in the coal bunker, as shown on the deck of the vessel.

Those interested in electrical devices will find a pleasing study in the drawings of the Haskell meter displayed in the chart room on the main deck.

The *Blake* has been anchored in depths of over 2 000 fathoms [12 000 feet] of water, and current observations have been successfully made with the Pillsbury meter at depths of from 3½ to 300 fathoms. The Haskell meter has not as yet been used often at depths exceeding 15 fathoms.

Other exhibits, surveying instruments, records, diagrams, etc., will be found in the chart room, appropriately labeled, and a very brief examination of these will serve to explain the connection of all of them with the Hydrographic Department of the Coast Survey.

Full descriptions of all the deep-sea apparatus exhibited on the *Blake* will be found in "Deep-Sea Sounding and Dredging," Sigsbee, 1880, and "Gulf Stream Investigations and Results," Pillsbury (Appendix No. 10, Report for 1890), both published by the U. S. Coast and Geodetic Survey.

WASHINGTON, D. C.

*May* 1, 1893.

# UNITED STATES COAST AND GEODETIC SURVEY.

**T. C. MENDENHALL, Superintendent.**

## MAGNETICS.

*The state of our knowledge of terrestrial magnetism at the time of Columbus, and the part taken in its development by the U. S. Coast and Geodetic Survey.*

At the time of the discovery of the western continent by Columbus the science of "terrestrial magnetism" had no existence. Beyond the ancient knowledge of the attraction of iron by a loadstone, and of its directive property little more was known in his day. In the region about the Mediterranean the magnetic needle was then pointing slightly to the east of the true meridian and the angle was supposed constant.

From the crude device of floating a magnetic needle the compass was gradually evolved. It seems probable that Columbus was quite satisfied to note his bearing within half a point.

When Drake sighted the coast of New Albion (California), in 1579, and Hudson on his third voyage skirted the Atlantic coast in 1609, their observations of the variation could not be depended upon closer than

about one-quarter of a point; the same is the case for the observations on the shores of the Gulf of Maine, by Champlain (1604–1612); however, when we come to the times of Bering (1727–1729), and of Cook (1768–1780), we find the probable uncertainty perhaps not more than $1\frac{1}{2}°$, and in our own time this uncertainty at sea, is still about 1°, owing to the extensive use of iron and steel in modern vessels. On land the declination of the needle may readily be measured within a single minute of arc, and in self-registering differential instruments, even to seconds.

Science owes to Columbus the discovery of a place where the needle pointed true north and south; this was on September 13, 1492, when he discovered that the variation had changed from the east to the west side of the meridian. The discovery of a second point, further north, is due to Sebastian Cabot (1497–1498), who found no variation 110 miles west of Flores (Azores).

Although variation data had been placed on charts more than half a century before Columbus, it was not earlier than the year 1700 that the mariner was provided with Halley's celebrated magnetic index chart. The dip of the magnetic needle did not become known until nearly half a century after the time of Columbus, it being discovered by Hartmann in 1544; nor had the idea of the measure of magnetic intensity entered men's minds, the accomplishment of which was reserved for Gauss, whose theory of terrestrial magnetism was published in 1838.

With the appearance of Gilbert's renowned work "De Magnete" in 1600, terrestrial magnetism was recognized as a distinct branch of science. This physicist was the first to announce the earth to be a great magnet, and it is with a study of its properties that investigators have ever since been busying themselves. Yet this boundary was too narrow and we owe, principally to Sabine, its extension known as cosmical magnetism. The magnetic phenomena as recognized here can be studied as the effect of transference of energy emanating from the sun, but like gravity, also interacting between bodies of the solar system.

The instruments by which the magnetic state of the earth is determined embrace those adapted for travelers by land or sea, and those for differential measures for the study of the minute variations.

*The declinometer.*—By its means we determine the angle, in a horizontal plane, which the direction of a magnetic needle makes with the true meridian. This angle is known as the "declination" (the "variation" of the mariner). Two specimens are on exhibition.

*The azimuth, or declination compass*, is provided with sights and used for the same purpose. One specimen is exhibited.

*The dip circle.*—By its means we determine the angle, in a vertical plane, by which the needle is inclined to the horizon, known as the dip or inclination. It is also provided with deflectors for the measure of relative total intensity. When specially fitted for use at sea, and for the measure of force, it is known as a "Fox circle". One specimen is on exhibition.

*The magnetometer.*—It is generally combined with the declinometer, and serves to measure the horizontal component of the magnetic force in absolute measure; hence, by combination with the dip the total force is ascertained.

A set of self-registering (by photography) instruments, consists of a *unifilar*, a *bifilar*, and a *balance* or *induction magnetometer*, measuring respectively the minute changes in declination and in the horizontal and vertical components of the intensity.

The important magnetic data necessarily inscribed on the Coast and Geodetic Survey charts made it imperative on the part of the Survey to observe, collect, and discuss the material thus secured. The more important facts and conclusions will be found in Appendices Nos. 6, 7, and 11 of Annual Reports, 1885, 1888, and 1889, respectively; also Nos. 8 and 9 of 1890, and No. 4 of 1891.

Four magnetic observatories have been maintained successively by the Survey. The total number of stations occupied is 897, and the number of observations collected and discussed amounts to several thousand.

We conclude with the description of two globes in the survey exhibit, illustrative of the distribution of the magnetic state of the earth's surface about the present time.

These globes have a diameter of one metre, hence they are about $\frac{1}{12\frac{3}{4}}$ millionth part of natural size. On each are shown two systems of magnetic curves, and it should be borne in mind that these curves are ever, yet slowly, changing their positions. *On globe No. 1* the red curves

known as isogonic lines refer to the declination, and the numbers attached give the angle in degrees. The areas where the north end of the needle points to the west of the meridian are tinted a buff color; the areas where the pointing is to the east are shown by a light blue color. The dividing line of the colors is called an agonic line where the needle points due north and south; it is seen to pass through the geographical as well as through the magnetic poles. The latter are approximately in north latitude 70¼° and west longitude 99°, and in south latitude 73½° and east longitude 146°. Here the horizontal needle has lost its directive force, and the vertical needle points directly up and down; that is, the directions of gravity and magnetic force coincide. The spectator will notice the singular oval over eastern Asia within which we have west declination.

The green curves indicate the strength of the horizontal part of the magnetic force known as "isodynamic lines" expressed in fractions of dynes (compare with 981 dynes, which is about the force of gravity at the earth's surface). Maximum value about 0.39 and zero at the magnetic poles. The regions where the total magnetic force is either a maximum (about $\frac{7}{10}$ dyne) or a minimum (about ¼ dyne) are called "foci". They are large and ill defined.

*Globe No. 2* exhibits in red curves "magnetic meridians"; *i. e.* lines that would be traced out by advancing in the direction of a compass needle. These lines converge to the magnetic poles, and everywhere show directly the pointing of the compass. The second system in green curves is known as "isoclinic lines", or lines of equal dip. North of the magnetic equator the areas are tinted light blue; south of it a buff color. These lines encircle the magnetic poles, where the needle is vertical, but inverted for the north and south poles. Along the equator it is horizontal.

WASHINGTON, D. C.;

*May* 1, 1893.

# UNITED STATES COAST AND GEODETIC SURVEY.

**T. C. MENDENHALL, Superintendent.**

## CHART PUBLICATIONS.

---

Charts are designed to assist the navigator and to subserve the interests of commerce. For purposes of navigation they may embrace large areas, like one of the great oceans or seas, delineating the conformation of the shores and outlying dangers, and perhaps indicating the principal currents and winds that may be utilized in determining the most advantageous routes between specified localities. For many regions special charts have been constructed to show the prevailing winds at different seasons of the year, and for some years past there has been issued from the Navy Department a monthly publication known as the "North Atlantic Pilot Chart", that forecasts the winds, ice floes, and fog belts, and portrays the routes of hurricanes, with directions for avoiding them, etc.; the position of all dangerous derelicts, and other information valuable to the navigator about to sail from port. Charts may also embrace much smaller areas, but on larger scales, permitting greater fullness of the detail, and thus presenting, graphically, the channels that can be followed, with the depths of the

water, the positions of lights, beacons, spindles, buoys, and other objects provided to indicate the way to the stranger. Charts of these classes are usually designated "Navigation charts", although they may also be useful for other purposes.

All classes of charts are necessarily an assistance to the advancement of commerce: those representing large areas as guides, and other classes delineating limited areas, such as harbors, roadsteads, anchorages, and the like, in presenting all the advantages and disadvantages of a locality, to meet an actual or prospective trade. These harbor charts or plans may exhibit every important detail of the harbor, and if based upon precise surveys, possess an additional value to the engineer for the study of physical conditions with a view to improvements, and for defensive purposes.

Nearly all civilized nations have published charts of their coast lines, in greater or less detail, and the principal maritime nations copy those issued by other nations, and thus maintain for the use of their own seamen charts of all parts of the world to which their commerce may extend. Great Britain maintains the most extensive establishment for the purpose and issues the most complete series of charts; she has also made the most extensive surveys of uncivilized coasts for cartographic purposes.

In the United States two Bureaus of the Government service are authorized to issue charts, but under restrictions that clearly define the duties of each and prevent unnecessary duplication; the Coast and Geodetic Survey in the Treasury Department, and the Hydrographic Office in the Navy Department. The former is charged with surveying the Atlantic, Gulf and Pacific coasts of the United States, including Alaska, and with researches to determine the origin and courses of the great ocean current known as the Gulf Stream, and to issue charts from these surveys suitable for the purposes of navigation, commerce, and the public defense; the latter, with the duplication of charts and plans issued by other nations, and the publication of surveys by our Navy on other coasts than our own. The Coast and Geodetic Survey issues four series of charts on the Atlantic and Gulf coasts of the United States, and three series on the Pacific coast, designated to subserve the purposes the surveys were established to meet. The first series is called "Sailing charts", and embraces long stretches

of coast, as from the Bay of Fundy to Cape Hatteras, Chesapeake Bay to the Bahamas, etc., and are intended to serve for offshore navigation, or between the greater headlands, as Cape Cod, Cape Hatteras, etc., and between distant harbors, as Boston to Chesapeake bay, Charleston, etc. They show only the outline of the continent, the seacoast lights, and geographic information that will be useful in using them for the purposes intended. The second series, or "General charts of the coast" is also designed for purposes of navigation; it is on a scale three times as large as the first series, and embraces more limited areas, as the Gulf of Maine, Gay Head to Cape Henlopen, Galveston to the Rio Grande, etc. These charts serve the navigator in coasting along shore between headlands, and in approaching harbors. The third series, or "Coast charts", embraces the whole coast on a uniform scale five times as large as the second series. Such charts are necessarily confined to comparatively short stretches of coast, as Sandy Hook to Barnegat, the entrance to Chesapeake bay, Mobile bay, etc. One inch on the paper represents about one and one-fourth statute miles, a scale sufficiently large to give the features of the topography and hydrography with great clearness, portraying the appearance of the coast and the irregularities of the bottom with a detail quite close enough for the navigation of the principal harbors. The fourth series consists of harbor charts on large scales intended to meet the needs of local navigation. On the Pacific coast the first series is similar to that on the Atlantic coast, and extends from San Diego to the Semidi Islands, Alaska; the second series is on a scale six times as large as the first, and is suitable for along shore navigation, and the inland passages of southeast Alaska. The third series includes charts on scales like those of the fourth series on the Atlantic coast.

All these series of charts are published from the same original surveys, the details of the original work being generalized or omitted to meet the requirements any particular series is intended to subserve. Various methods are available for producing charts of these classes, but experience has demonstrated that on coasts like large portions of those of the United States, which are subject to frequent changes, from natural causes, necessitating extensive corrections, engravings upon copper are the most expedient and economical. The

engravings afford the additional advantage of being readily duplicated by the electrotyping process. All the standard charts issued by the Bureau are therefore copper-plate engravings. Preliminary editions, however, are frequently issued by means of the "photolithograph process", which affords a cheap and ready method for temporary purposes.

In the exhibit will be found all classes of the charts referred to. The general method of constructing and producing them is shown by special plates. First, there is a model of Carmel Bay, California, with the original sheets of the topographic and hydrographic surveys; a drawing reduced from these sheets and the photolithographic chart made from the drawing. In the second section there is exhibited a topographic sheet of the vicinity of Calais, on the St. Croix river, Maine, with the principal processes employed to produce the final engraving upon copper, with a print from the engraved copper plate. Also a plate of the same locality on one-half the scale, representing the relief by hachures instead of by horizontal curves. The "photolithographic process" is shown by drawings on different scales with prints reduced to the same scale; and a third process is exhibited by a lithographic stone, showing a transfer from the copper plate and a print made from the stone. These methods of reproduction are followed by samples of the charts of Hampton Roads, Virginia, and San Francisco Entrance, California, on various scales, showing the availability of different scales in representing detail.

The Survey publishes about 450 charts, with an average annual issue of 52,000 copies.

WASHINGTON, D. C.,
*May* 1, 1893.

# UNITED STATES COAST AND GEODETIC SURVEY.

**T. C. MENDENHALL, Superintendent.**

## WEIGHTS AND MEASURES.

"Divers weights, and divers measures, both of them are alike abomination to the Lord." Prov. xx.

"There shall be but one uniform standard of weights, measures, and manufactures." Magna Charta, Sec. 35.

Congress shall have power "to fix the standard of weights and measures." U. S. Constitution, Art. 1, Sec. 8.

Reference to scripture and secular law shows that it is one of the first duties of Government to define the weights and measures which may be used in the commercial transactions of daily life, in order to secure justice to all individuals in their dealings with the Government or with each other.

As everybody has a material interest in the correctness of weights and measures by which things are bought and sold, and as the increase of human knowledge largely depends on accurate weights and measures, it is a subject of universal concern.

The importance of securing and maintaining their uniformity has been recognized by our most eminent statesmen. Washington urged

the necessity of suitable legislation, Jefferson made a report on weights and measures in 1790, and John Quincy Adams made an elaborate one in 1821. In this he proposed to make the customary standards uniform, excluding innovation, until consultation with foreign nations should secure the establishment of universal and permanent uniformity.

In 1831 the Treasury Department adopted certain standards for use in the Customhouses, and in 1836 Congress ordered the construction of similar standards for distribution to the States. Balances were also constructed and furnished.

The Office of Standard Weights and Measures is a branch of the Treasury Department. Its function is to guard and preserve the United States standards; to furnish such copies as may be prescribed by law to the several States of the Union; to re-compare, when necessary, standards thus furnished, with their prototypes; to verify weights and measures used in the Customs and Internal Revenue services, and by other branches of the Government, and to serve the public generally as intermediary when reference is required to the national standards.

The United States weights and measures now in common use in this country were brought from England before the Revolution. They are—the Yard, Pound Avoirdupois, Pound Troy, Gallon of 231 cubic inches, Bushel of 2150·42 cubic inches.

The Troy pound of the Mint has been declared by Congress to be the standard according to which the coinage shall be regulated. All the other standards above mentioned were adopted by the Treasury and copies were distributed to the several States.

METRIC STANDARDS.

In 1866 the use of the metric system was made lawful in this country, and the legal equivalence between it and the customary system was established essentially as follows: Yard = ·914402 metres; pound troy = 0·3732418 kilogrammes; pound avoirdupois = 0·4535924 kilogrammes; gallon = 3·78543 litres; bushel = 35·239 litres. Standards of these denominations were also furnished to the State governments.

The advantages accruing from the use of international weights and measures have led the principal governments of the world, among them the United States, to establish and maintain at Paris, France, an

International Bureau of Weights and Measures. In its keeping are a metre and a kilogramme belonging to the nations, conjointly, which maintain the Bureau. Exact copies of the international prototypes, as they are called, have been furnished to the several nations. Thus it has come about that a common standard of length and weight for these nations has been established.

The exhibit shows a metre made under the direction of the International Bureau. In appearance it is exactly like the international prototype. The lines defining its length are ruled on the neutral surface. It is an alloy of platinum iridium. The case in which it is preserved is shown, as well as a standard thermometer, also made under the direction of the International Bureau. The glass bell which is exhibited was devised for preserving the prototype kilogrammes.

## WEIGHTS AND MEASURES FOR THE STATES.

### CUSTOMARY.

These, including the balances, were prepared at the Office of Standard Weights and Measures, in Washington, between 1836 and 1850. Some of the weights shown have recently been electro-gilded. A full set is here exhibited.

*Measures of length.*—A line yard divided into feet and inches; an end yard fitting into a matrix.

*Weights.*—A set of avoirdupois weights from 50 to 1 pound, and a smaller set from 8 oz. to ⅛ oz.

One pound Troy and Troy oz. from 1 oz. to 0·0001 oz.

One set of grain weights from 50 grs. to 0·1 grs.

*Liquid measure.*—A gallon, half gallon, quart, pint, and half pint.

*Dry measure.*—A half bushel.

### METRIC.

These were made in response to the joint resolution of Congress of July, 1866.

*Measures of length.*—A steel end metre; a brass line metre divided to 0 1 and 0·001 metre.

*Weights.*—A dekakilogramme, kilogramme, demi-kilogramme, and gramme of brass, and subdivision of the gramme in silver to 0·001.

*Capacity measure.*—A litre and a dekalitre.

MURAL OR BENCH STANDARD.

The United States bench standard, at Washington, for comparing chains and steel tapes, is twice as long as the one here exhibited.

The essential part of a standard of this pattern is an iron bar carrying a graduation in feet or metres, traced on German-silver plugs let into the bar. The graduation is made by means of an auxiliary iron bar carrying a tracing apparatus.

The advantage of having an iron bar for a bench standard is that its coefficient of expansion is nearly the same as that of steel tapes or chains, and that, therefore, comparisons can be made under ordinary conditions without regard to temperature, provided the temperature at which the bench standard is correct has been found.

THERMOMETER COMPARATOR.

For comparing thermometers in a horizontal position in liquid.

HOLLOW SPHERE.

Mass, 1 kilogramme; volume, 1 litre. Used in adjusting litres, or, as an auxiliary instrument in weighing, instead of thermometer, barometer, and psychrometer, to determine the buoyancy of air.

VAPOR MANOMETER.

To determine the pressure of aqueous vapor in the air by drying the air in one globe with sulphuric acid.

SAXTON'S PYROMETER.

Devised by Joseph Saxton, in 1839, for determining the expansion of bars of metal. The expanding bar turns a mirror, the angular motion of which is read off on a scale by means of a telescope.

WASHINGTON, D. C.,
*May 1, 1893.*

# UNITED STATES COAST AND GEODETIC SURVEY.

**T. C. MENDENHALL, Superintendent.**

## MODEL OF UNITED STATES AND ALASKA.

---

This model is constructed to represent the United States and Alaska as if they were cut out from a sphere about 42 feet in diameter.

The various dimensions of the physical features shown on its surface are thus diminished to one-millionth their natural size. For convenience of transportation the model has been built in eight sections. Of these the United States occupies four, each 15° of longitude in width; and Alaska three, each 20° of longitude in width. The eighth is long and narrow, 34° of latitude and 10° of longitude, and forms the connecting link between these two portions.

The position of the model is so arranged that the axis of the spheroid, from which it is supposed to be taken, is perpendicular to the floor, with the North Pole upward.

Contrary to the usual custom pursued in making relief maps, the vertical scale adopted is the same as that for horizontal distances. This means that the heights of the mountains and plateaus have not been exaggerated for pictorial effect, but retain in this respect their

true proportion in reference to their bases. The elevations are built up with layers of prepared cardboard. Each layer is twelve one-thousandths of an inch (0.012 inch) thick, and represents an increase of height above sea level of one thousand feet. Thus Mt. Washington, N. H., which is 6,000 feet high, requires six layers, while Pikes Peak, 14,000 feet, and Mt. St. Elias, 18,000 feet, require fourteen and eighteen layers, respectively.

The edges of these successive steps being left sharply cut and perpendicular, serve to mark the lines of equal elevation, and correspond to the contours of a topographical map.

To assist the eye in obtaining a clearer view of the modelling of the mountain chains, the shadows have been imitated which they would cast with the sun low in the west.

Lines of equal depth have been drawn in the Atlantic and Pacific oceans and the Gulf of Mexico, for intervals of 1,000 feet. The wide space between the shore and the first line indicates the position of the submerged portion of the continental plateau. Where they are closely grouped are found the steep inclines which lead to the ocean floor.

At numerous points magnetic needles have been mounted, and the magnetic field in their neighborhood is made to resemble that actually existing on the earth, so that each shows the direction in which a compass needle points in the locality corresponding to its position on the model. By this means a rough idea can be obtained of the variations of the magnetic declination throughout our territory.

The character and progress of the primary triangulation of the survey is shown by the red lines forming geometrical figures, which cover irregular areas along the Atlantic and Pacific coasts, and which extend, in a nearly continuous chain, across the continent along the 39th parallel.

Several lines converging to a single point indicate the location of a station of the triangulation, which is generally situated on a mountain top or other commanding elevation. At each station horizontal directions are measured to all stations with which it is connected; and from these observations, together with measured bases, the distances from point to point are computed. The actual measures on the ground or bases are indicated by small lengths of brass wire. These triangulation

lines illustrate the difference between the methods employed for surveys of a geodetic character and those employed for surveys of lands and railroads.

In the latter the measurements are made and computed as if the earth were one vast plane. In the former, owing to the greater distances spanned, the figure of the earth has to be taken into consideration, and hence the necessity for more refined instrumental methods, and more complex formulas.

The yellow lines show the routes over which precise levels have been carried to furnish data used in triangulation computations, and also planes of reference for the coördination of State topographical surveys.

It is believed that this model will serve to correct some erroneous impressions entertained by those whose knowledge of the earth's surface has been derived from customary sources. The elevated portions of a continent have such a controlling influence on its climate, its political and social conditions, that a map or model on which they could not be plainly discerned would be of little value.

Therefore, when the representation is on a small scale, exaggeration of the relief must be resorted to to make it visible at all. Notwithstanding the gain in this direction, it should be remembered that it is accomplished at the expense of a clear perception of the horizontal distances.

The shading of the mountains in our text books, and the exaggeration of the vertical scale in the usual relief models, both tend to give an exalted notion of the height and mass of mountain chains utterly out of proportion to the expanse of territory in which they are situated. These representations also contribute to distract the attention from the symmetrical curve of the earth's surface; a curve of such magnitude that mountains and valleys merely roughen the smoothness of its line.

It may be interesting in this connection to call attention to the insignificance of all vertical compared to horizontal distances within the sphere of man's action.

Vertically, he is confined to very narrow limits, by the absence, outside of these limits, of conditions favorable to the support of life. Horizontally, he can travel thousands of miles around the earth, but

can ascend above it scarcely six miles, or penetrate below its surface more than one.

In comparison with the size of the earth the atmosphere extends but a very short distance above us. That portion having sufficient density to be effective in producing positive results, being estimated to have a height of only 40 miles, or two and a half inches on the scale of this model; and the storm-producing strata are mere films, seldom reaching to the height of the highest mountain chains; or a quarter of an inch on this scale.

According to the theory held by many geologists, 25 or 30 miles below the surface of the earth commences the liquid substratum, where the heat is so intense as to melt the most refractory substances. At the speed of one of our fast railroad trains one could accomplish this distance in half an hour, and on the scale of this model two inches would represent that depth. To further illustrate this point of view, the following vertical distances are given with the corresponding measures on the model.

| | | MODEL. |
|---|---|---|
| | *Feet.* | *Inch.* |
| Greatest depth of ocean (Pacific) | 28 000 | 0·336 |
| Highest mountain in North America (St. Elias) | 18 000 | ·216 |
| Deepest well in North America (Wheeling, W.Va.) | 4 500 | ·054 |
| Deepest mine in North America (Comstock, Nev.) | 3 000 | ·036 |
| Highest structure, Washington Monument | 550 | ·007* |
| Highest tide, Bay of Fundy | 50 | ·0006 |

In contrast with the above minute vertical distances, an air line from Key West, at the southern end of Florida, to Attu, the island at the western limit of our possessions in Alaska, is 5 500 miles, or 348½ inches on the scale of this model.

WASHINGTON, D. C.,
*May 1, 1893.*

* Hardly thicker than a sheet of writing paper.

UNITED STATES

COAST AND GEODETIC SURVEY.



T. C. MENDENHALL,

SUPERINTENDENT.

BULLETIN No. 30.

# UNITS

OF

# ELECTRICAL MEASURE.

APPROVED FOR PUBLICATION DECEMBER 27, 1893.

Bulletins are issued by the Survey from time to time as material for them accumulates. They are intended to give early announcement of work accomplished or information of importance obtained, and will in many cases anticipate the usual means of publication afforded by the Annual Reports. Those already published, Nos. 1 to 25 inclusive, in quarto form, have their pages numbered consecutively and constitute Vol. I. No. 26 began Vol. II, which will be published in octavo.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1894.

2—1724

# UNITS OF ELECTRICAL MEASURE.

Within but little more than a decade, practical applications of electricity have developed with a rapidity unparalleled in the history of modern industries. Many millions of dollars of capital are now invested in the manufacture of machinery and various devices for the production and consumption of electricity. As it has now become a commodity of trade, its measurement is a question of the highest importance, both to the producer and consumer. Both the nomenclature of electro-technics and the methods and instruments of measure are exceptionally precise and satisfactory, but there has been lacking, up to the present time, the very important and essential element of fixed and invariable units of measure authoritatively adopted. Such units have long been in use among scientific men, but the necessity for the establishment and legalization of practical units for commercial purposes became evident in the beginning of the recent enormous development of the applications of electricity.

To meet this universally recognized want, conferences and congresses of the leading electricians of the world have been held at occasional intervals, the first being the Paris Congress of 1881. These assemblages have been international in their character, for it was wisely determined in the beginning that the new units of measure should be international and, indeed, universal in their application. It was convenient to make them so, and it was important to thus facilitate international interchange of machinery, instruments, etc. The United States was represented by official delegates in the Congress of 1881, and also in subsequent Congresses in 1884.

The difficulty of the material representation of some of the units of measure was so great at the time of holding these Congresses that no satisfactory agreement as to all of them could be arrived at. Some recommendations were made, but they at no time received the unanimous support of those interested and were admitted by all to be tentative in their character. During the past few years the advance of knowledge and experience among electricians was such as to indicate that the time was ripe for the general adoption of the principal units of electrical measure. An International Congress of Electricians was arranged for, to meet in Chicago, during the World's Columbian Exposition of 1893. In this Congress the bus-

iness of defining and naming units of measure was left to what was known as the "Chamber of Delegates," a body composed of those only who had been officially commissioned by their respective governments to act as members of said Chamber. The United States, Great Britain, Germany, and France were each allowed five delegates in the Chamber. Other nations were represented by three, two, and in some cases one. The principal nations of the world were represented by their leading electricians, and the Chamber embraced many of the most distinguished living representatives of physical science.

The delegates representing the United States have reported to the Honorable the Secretary of State, under date of November 6, 1893, giving the names and definitions of the units of electrical measure as unanimously recommended by the Chamber in a resolution as follows:

"*Resolved*, That the several governments represented by the delegates of this International Congress of Electricians be, and they are hereby, recommended to formally adopt as legal units of electrical measure the following: As a unit of resistance, the *international ohm*, which is based upon the ohm equal to $10^9$ units of resistance of the Centimetre-Gramme-Second system of electro-magnetic units, and is represented by the resistance offered to an unvarying electric current by a column of mercury at the temperature of melting ice 14·4521 grammes in mass, of a constant cross-sectional area and of the length of 106·3 centimetres.

"As a unit of current, the *international ampère*, which is one-tenth of the unit of current of the C. G. S. system of electro-magnetic units, and which is represented sufficiently well for practical use by the unvarying current which, when passed through a solution of nitrate of silver in water, and in accordance with accompanying specifications,* deposits silver at the rate of 0·001118 of a gramme per second.

"As a unit of electro-motive force, the *international volt*, which is the electro-motive force that, steadily applied to a conductor whose resistance is one international ohm, will produce a current of one

* In the following specification, the term silver voltameter means the arrangement of apparatus by means of which an electric current is passed through a solution of nitrate of silver in water. The silver voltameter measures the total electrical quantity which has passed during the time of the experiment, and by noting this time, the time average of the current, or if the current has been kept constant, the current itself can be deduced.

In employing the silver voltameter to measure currents of about one ampère, the following arrangements should be adopted:

The kathode on which the silver is to be deposited should take the form of a platinum bowl, not less than 10 centimetres in diameter and from 4 to 5 centimetres in depth.

The anode should be a plate of pure silver some 30 square centimetres in area and 2 or 3 millimetres in thickness.

This is supported horizontally in the liquid near the top of the solution by a platinum wire passed through holes in the plate at opposite corners. To prevent the disintegrated silver which is formed on the anode from falling on to the kathode, the anode should be wrapped round with pure filter paper, secured at the back with sealing wax.

The liquid should consist of a neutral solution of pure silver nitrate, containing about 15 parts by weight of the nitrate to 85 parts of water.

The resistance of the voltameter changes somewhat as the current passes. To prevent these changes having too great an effect on the current, some resistance besides that of the voltameter should be inserted in the circuit. The total metallic resistance of the circuit should not be less than 10 ohms.

international ampère, and which is represented sufficiently well for practical use by $\frac{1000}{1434}$ of the electro-motive force between the poles or electrodes of the voltaic cell known as Clark's cell, at a temperature of 15° C., and prepared in the manner described in the accompanying specification.†

"As a unit of quantity, the *international coulomb*, which is the quantity of electricity transferred by a current of one international ampère in one second.

"As a unit of capacity, the *international farad*, which is the capacity of a condenser charged to a potential of one international volt by one international coulomb of electricity.

"As a unit of work, the *joule*, which is equal to $10^7$ units of work in the C. G. S. system, and which is represented sufficiently well for practical use by the energy expended in one second by an international ampère in an international ohm.

"As a unit of power the *watt*, which is equal to $10^7$ units of power in the C. G. S. system, and which is represented sufficiently well for ~~practical~~ the work done at the rate of one joule per second.

"As the unit of induction, the *henry*, which is the induction in a circuit when the electro-motive force induced in this circuit is one international volt, while the inducing current varies at the rate of one ampère per second."

Besides the fact that the Congress in which this important and far-reaching action was taken was held in the United States, our country has been honored by the action of the Chamber of Delegates in placing in the list of the illustrious names which are to be perpetuated in the nomenclature of electricity that of our countryman, Joseph Henry, whose splendid contributions to science, made about sixty years ago, have only in recent years met with full recognition. For these and other reasons it is extremely desirable that our Government should be among the first, if not the first, to adopt the recommendations of the Chamber. To make the use of these units obligatory in all parts of the country will require an act of Congress, but in the absence of that, it is within the power of the Secretary of the Treasury to approve their adoption for use in all Departments of the Government. This, indeed, is precisely the course long ago followed in reference to the ordinary weights and measures of commerce and trade. Congress has never enacted a law fixing the value of their units, but the Secretary of the Treasury was authorized to establish and construct standards for use in the various Departments of the Government. Uniformity has followed on account of the universal adoption of these standards by the several States.

The Government is itself a large consumer of electricity and electrical machinery, and for its own protection it is important that units of measure be adopted. With the approval, therefore, of the

† A committee, consisting of Messrs. Helmholtz, Ayrton, and Carhart, was appointed to prepare specifications for the Clark's cell. Their report has not yet been received.

Honorable the Secretary of the Treasury, the formal adoption by the Office of Standard Weights and Measures of the names and values of units of electrical measure as given above, the same being in accord with the recommendations of the International Congress of Electricians of 1893, is hereby announced.

T. C. MENDENHALL,
*Superintendent U. S. Coast and Geodetic Survey, and of Standard Weights and Measures.*

Approved:

J. G. CARLISLE,
*Secretary of the Treasury.*

2—1724

Second. The unit of current shall be what is known as the international ampere, which is one-tenth of the unit of current of the centimetre gramme-second system of electro-magnetic units, and is the practical equivalent of the unvarying current, which, when passed through a solution of nitrate of silver in water in accordance with standard specifications, deposits silver at the rate of one thousand one hundred and eighteen millionths of a gramme per second.

Third. The unit of electro-motive force shall be what is known as the international volt, which is the electro-motive force that, steadily applied to a conductor whose resistance is one international ohm, will produce a current of an international ampere, and is practically equivalent to one thousand fourteen hundred and thirty-fourths of the electro-motive force between the poles or electrodes of the voltaic cell known as Clark's cell, at a temperature of fifteen degrees centigrade, and prepared in the manner described in the standard specifications.

Fourth. The unit of quantity shall be what is known as the international coulomb, which is the quantity of electricity transferred by a current of one international ampere in one second.

Fifth. The unit of capacity shall be what is known as the international farad, which is the capacity of a condenser charged to a potential of one international volt by one international coulomb of electricity.

Sixth. The unit of work shall be the joule, which is equal to ten million units of work in the centimetre-gramme-second system, and which is practically equivalent to the energy expended in one second by an international ampere in an international ohm.

Seventh. The unit of power shall be the watt, which is equal to ten million units of power in the centimetre-gramme-second system, and which is practically equivalent to the work done at the rate of one joule per second.

Eighth. The unit of induction shall be the henry, which is the induction in a circuit when the electro-motive force induced in this circuit is one international volt while the inducing current varies at the rate of one ampere per second.

SEC. 2. That it shall be the duty of the National Academy of Sciences to prescribe and publish, as soon as possible after the passage of this Act, such specifications of details as shall be necessary for the practical application of the definitions of the ampere and volt hereinbefore given, and such specifications shall be the standard specifications herein mentioned.

Approved, July 12, 1894.

TREASURY DEPARTMENT,

UNITED STATES COAST AND GEODETIC SURVEY.

W. W. DUFFIELD,

SUPERINTENDENT.

BULLETIN No. 32.

# THE CONSTANT OF ABERRATION

AS DETERMINED FROM

## OBSERVATIONS OF LATITUDE

AT

## SAN FRANCISCO, CALIFORNIA.

Discussion and report by E. D. PRESTON, ASSISTANT.

Observations by GEORGE DAVIDSON, ASSISTANT.

Submitted for publication October 30, 1894.

Bulletins are issued by the Survey from time to time as material for them accumulates. They are intended to give early announcement of work accomplished or information of importance obtained, and will in many cases anticipate the usual means of publication afforded by the Annual Reports. Those already published, Nos. 1 to 25 inclusive, in quarto form, have their pages numbered consecutively and constitute Vol. I. No. 26 begins Vol. II, which will be published in octavo.

WASHINGTON:

GOVERNMENT PRINTING OFFICE.

1895.

# THE CONSTANT OF ABERRATION AS DETERMINED FROM OBSERVATIONS OF LATITUDE AT SAN FRANCISCO, CALIFORNIA.

E. D. PRESTON, ASSISTANT.

The refined methods employed during the last few years in studying the changes of latitude have incidentally thrown light on one of the fundamental constants of astronomy. Continuous measures of small differences of zenith distances, carried on with a view of detecting a suspected motion of the pole, furnish material for the determination of the effect of aberration. The long series of observations made in Waikiki, Hawaiian Islands, in 1891 and 1892, were discussed for this purpose, and now the still longer series made by Professor Davidson at San Francisco have been subjected to the same treatment. The methods, however, were essentially different. Both are due to Professor Newcomb, and the work of computation has been done in the Coast and Geodetic Survey Office partly by myself and partly by Mr. C. C. Yates under my supervision.

In the Waikiki observations an attempt was made to determine simultaneously the variations of latitude and a correction to the constant of aberration. This involved the formation and solution of 2 370 conditional equations of the form—

$$z + x \cos N + y \sin N + A\rho = \Delta\varphi.$$

The result fully justified the method. The latitude curve agreed almost precisely with that found by an independent treatment according to the German method, and a very fair value was deduced for the correction $\rho$. The details of this work are given in Bulletin No. 28, U. S. Coast and Geodetic Survey.

In the San Francisco observations, with which this paper has to do, it was desirable to shorten the labor, because here we have nearly 7 000 conditional equations. To apply the method of least squares for the purpose of determining four unknown quantities to such a mass of data would require great labor. The periodic variations of latitude were therefore accepted as already deduced by Mr. C. A. Schott, and the conditional equations were formed containing only two unknown quantities, one of which was the correction to the aberration constant.

The following groups of stars were observed:

| Group. | Right Ascension. | Period of Observation. | Mean Date (1891-1892). |
|---|---|---|---|
| | h. m. h. m. | | |
| I | 14 1 to 17 4 | May 27, 1891, to July 1, 1891 | June 13 |
| | | Mar. 6, 1892, to June 5, 1892 | April 21 |
| II | 17 10 to 20 3 | May 27, 1891, to Aug. 13, 1891 | July 5 |
| | | May 10, 1892, to Aug. 19, 1892 | June 30 |
| III | 20 10 to 23 2 | July 4, 1891, to Sept. 22, 1891 | Aug. 13 |
| | | July 30, 1892, to Aug. 19, 1892 | Aug. 10 |
| IV | 23 10 to 2 3 | Aug. 15, 1891, to Oct. 30, 1891 | Sept. 22 |
| V | 2 6 to 5 1 | Sept. 23, 1891, to Dec. 2, 1891 | Oct. 8 |
| VI | 5 6 to 8 8 | Nov. 5, 1891, to Jan. 23, 1892 | Dec. 14 |
| VII | 8 12 to 11 3 | Dec. 17, 1891, to Mar. 8, 1892 | Jan. 27 |
| VIII | 11 20 to 13 58 | Jan. 27, 1892, to May 7, 1892 | Mar. 18 |

The equation furnished by Mr. Schott was as follows:

$$\text{Latitude} = \varphi = 37^\circ\, 47'\, 28''\cdot334 + 0''\cdot172 \sin\left(\frac{360^\circ}{431}\, t + 3^\circ\cdot7\right)$$
$$+ 0''\cdot074 \sin\left(\frac{360}{365\frac{1}{4}}\, t + 20^\circ\cdot5\right),$$

where $t$ is the number of days from January 0, 1891.

The foregoing equation gives the following values for the latitude from May 29, 1891, to August 21, 1892.

The tabular values are to be added to $37^\circ\, 47'\, 20''$ to get the actual values.

| Date. | Latitude. | Date. | Latitude. | Date. | Latitude. |
|---|---|---|---|---|---|
| 1891. | " | 1891. | " | 1891. | " |
| May 29 | 8·48 | Aug. 12 | 8·24 | Oct. 26 | 8·12 |
| June 3 | ·47 | 17 | ·22 | 31 | ·12 |
| 8 | ·46 | 22 | ·21 | Nov. 5 | ·12 |
| 13 | ·44 | 27 | ·19 | 10 | ·13 |
| 18 | ·42 | Sept. 1 | ·18 | 15 | ·13 |
| 23 | ·41 | 6 | ·17 | 20 | ·14 |
| 28 | ·39 | 11 | ·16 | 25 | ·14 |
| July 3 | ·37 | 16 | ·15 | 30 | ·15 |
| 8 | ·35 | 21 | ·14 | Dec. 5 | ·16 |
| 13 | ·34 | 26 | ·13 | 10 | ·17 |
| 18 | ·32 | Oct. 1 | ·13 | 15 | ·18 |
| 23 | ·30 | 6 | ·12 | 20 | ·20 |
| 28 | ·28 | 11 | ·12 | 25 | ·21 |
| Aug. 2 | ·27 | 16 | ·12 | 30 | ·22 |
| 7 | ·25 | 21 | ·12 | | |

| Date. | Latitude. | Date. | Latitude. | Date. | Latitude. |
|---|---|---|---|---|---|
| 1892. | ″ | 1892. | ″ | 1892. | ″ |
| Jan. 4 | 8·24 | Mar. 24 | 8·46 | June 12 | 8·50 |
| 9 | ·25 | 29 | ·47 | 17 | ·50 |
| 14 | ·27 | Apr. 3 | ·48 | 22 | ·49 |
| 19 | ·28 | 8 | ·49 | 27 | ·48 |
| 24 | ·30 | 13 | ·50 | July 2 | ·48 |
| 29 | ·31 | 18 | ·50 | 7 | ·47 |
| Feb. 3 | ·33 | 23 | ·51 | 12 | ·46 |
| 8 | ·34 | 28 | ·51 | 17 | ·45 |
| 13 | ·36 | May 3 | ·52 | 22 | ·44 |
| 18 | ·37 | 8 | ·52 | 27 | ·42 |
| 23 | ·39 | 13 | ·52 | Aug. 1 | ·41 |
| 28 | ·40 | 18 | ·52 | 6 | ·40 |
| Mar. 4 | ·41 | 23 | ·52 | 11 | ·39 |
| 9 | ·43 | 28 | ·51 | 16 | ·38 |
| 14 | ·44 | June 2 | ·51 | 21 | ·36 |
| 19 | ·45 | 7 | ·51 | | |

When the preceding values are compared with those resulting from observation the outstanding differences represent the combined effect of two independent quantities. One is the correction to reduce the mean declination of each pair of stars to the mean of all the pairs and the other a certain function of the quantity $20''{\cdot}4451$, which is the aberration constant, and which appears as a factor in two terms of the reductions from the mean to the apparent place of the stars. The tabular values are considered applicable for two days on each side of the date given. Each directly observed latitude will therefore furnish an equation of the form—

$$C + Kx = \Delta\varphi$$

where $C$ is the correction to the mean declination of the pair,

$K$ is the sum of $h \cos (H + a) \sin \delta + i \cos \delta$ for both stars,

$x$ is minus ½ the factor by which the aberration constant used in the reduction must be multiplied in order to get the correction to this constant, and

$\Delta\varphi$ is the difference between the observed value of the latitude and the mean latitude plus its periodic variation.

Each pair will then give conditional equations of the form—

$$\begin{aligned} C + K_1 x &= \Delta_1 \varphi \\ C + K_2 x &= \Delta_2 \varphi \qquad\qquad (1.) \\ C + K_3 x &= \Delta_3 \varphi, \\ \text{etc.,} \quad & \quad \text{etc.,} \end{aligned}$$

where each equation corresponds to a separate observation.

If there are $n$ observations the normal equations for this pair will be—

$$n\,C + \quad [K]\;x = [\varDelta\varphi]$$
$$[K]\;C + [KK]\;x = [K\,\varDelta\varphi]$$

from which by eliminating $C$—

$$x = \frac{[K\,\varDelta\varphi] - \dfrac{[K]\,[\varDelta\,\varphi]}{n}}{[K\,K] \;-\; \dfrac{[K]^2}{n}} \qquad (2.)$$

This is the direct method. In practice, however, as Professor Newcomb suggested, each $K$ was multiplied by 0·04, so as to make the general mean somewhat less than unity, which procedure gave a value of $x$ 25 times greater than its true value. The value found from the normal equations is therefore to be divided by 25.

In the solution by the above scheme the declination correction disappears, and we have finally 6 768 equations containing only $x$ and known terms. A mean equation gives the value sought.

The interpretation of the result is easily made by considering the form of the conditional equations and the relation between the coefficient of $x$ and the aberration constant.

The quantity $20''\cdot4451$ enters as a factor into the expression $h\cos(H + a)\sin\delta + i\cos\delta$, or, in Bessel's notation, into $C\,c' + D\,d'$. This expression is added to the declination of each star in finding its apparent place, and the latitude comes from summing the declinations and dividing by two. Hence, any change in the above factor affects the deduced latitude by only half as much, and since $\varDelta\,\varphi$ is equal to $\varphi - \varphi_0$, or to the observed latitude minus the mean latitude corrected for periodic variation, the effect on $\varDelta\,\varphi$ is equal to its effect on $\varphi$ and is of the same sign. Moreover the sign of $x$ must be opposite to the sign of the correction to $20''\cdot4451$, since the term $+ K\,x$ represents the excess of the $\varDelta\,\varphi$ deduced with this value over that which would come from using the new value.

In general, if the value of $x$, as used in the equations, comes out $+ a$, the correction to be applied to the constant of aberration is $- 1\cdot64\,a$, or the value of the aberration constant given by the observations is—

$$20''\cdot4451 - 20\cdot4451\left(\frac{2\,a}{25}\right)$$

In forming the coefficients for determining $x$, each group was taken up separately, and the quantities were tabulated according to the following scheme, where all numbers are given for the first pair of Group I:

PAIR I₁.

| 1891. | Δ φ | K | K² | K Δ φ | 1892. | Δ φ | K | K² | K Δ φ |
|---|---|---|---|---|---|---|---|---|---|
| | " | | | | | " | | | |
| May 28 | +0·62 | + 0·4 | 0·16 | +0·25 | Mar. 6 | +0·58 | — 1·0 | 1·00 | —0·58 |
| 29 | —0·12 | 0·4 | 0·16 | —0·05 | 12 | —0·10 | 1·0 | 1·00 | +0·10 |
| June 1 | +0·11 | 0·4 | 0·16 | +0·04 | 20 | —0·50 | 0·9 | 0·81 | +0·45 |
| 3 | +0·85 | 0·5 | 0·25 | +0·42 | 21 | +0·10 | 0·8 | 0·64 | —0·08 |
| 5 | —0·01 | 0·5 | 0·25 | 0·00 | 22 | —0·13 | 0·8 | 0·64 | +0·10 |
| 6 | —0·32 | 0·5 | 0·25 | —0·16 | 23 | —0·05 | 0·8 | 0·64 | +0·04 |
| 7 | +0·18 | 0·6 | 0·36 | +0·11 | 24 | —0·79 | 0·8 | 0·64 | +0·63 |
| 8 | +0·12 | 0·6 | 0·36 | +0·07 | 25 | —0·24 | 0·8 | 0·64 | +0·19 |
| 12 | +0·27 | 0·6 | 0·36 | +0·16 | 27 | —0·23 | 0·8 | 0·64 | +0·18 |
| 13 | —0·01 | 0·6 | 0·36 | —0·01 | 29 | +0·15 | 0·7 | 0·49 | —0·10 |
| 14 | —0·09 | 0·7 | 0·49 | —0·06 | 30 | —0·51 | 0·7 | 0·49 | +0·36 |
| 17 | —0·56 | 0·7 | 0·49 | —0·39 | Apr. 3 | —0·24 | 0·6 | 0·36 | +0·14 |
| 18 | +0·54 | 0·7 | 0·49 | +0·38 | 4 | +0·07 | 0·6 | 0·36 | —0·04 |
| 19 | 0·00 | 0·8 | 0·64 | 0·00 | 5 | +0·38 | 0·6 | 0·36 | —0·23 |
| 20 | —0·53 | 0·8 | 0·64 | —0·42 | 9 | —0·03 | 0·5 | 0·25 | +0·02 |
| 21 | —0·14 | 0·8 | 0·64 | —0·11 | 11 | +0·35 | 0·5 | 0·25 | —0·17 |
| 22 | +0·01 | 0·8 | 0·64 | +0·01 | 15 | +0·01 | 0·4 | 0·16 | 0·00 |
| 25 | +0·54 | 0·8 | 0·64 | +0·43 | 16 | —0·28 | 0·4 | 0·16 | +0·11 |
| 26 | +0·29 | 0·8 | 0·64 | +0·23 | 17 | —0·24 | 0·4 | 0·16 | +0·10 |
| 27 | +0·57 | 0·9 | 0·81 | +0·51 | 18 | —0·16 | 0·4 | 0·16 | +0·06 |
| 28 | +0·02 | 0·9 | 0·81 | +0·02 | 19 | +0·24 | 0·4 | 0·16 | —0·10 |
| 29 | +0·45 | 0·9 | 0·81 | +0·40 | 21 | —0·35 | 0·3 | 0·09 | +0·10 |
| | | | | | 22 | —0·35 | 0·3 | 0·09 | +0·10 |
| | | | | | 24 | +0·15 | 0·3 | 0·09 | —0·04 |
| | | | | | 25 | —0·19 | 0·2 | 0·04 | +0·04 |
| | | | | | 26 | —0·17 | 0·2 | 0·04 | +0·03 |
| | | | | | May 8 | —0·41 | 0·0 | 0·00 | 0·00 |
| Sums | +2·79 | +14·7 | 10·41 | +1·83 | Sums | —2·94 | —15·2 | 10·36 | +1·41 |

PAIR I₁.

| 1892. | Δ φ | K | K² | K Δ φ | 1892. | Δ φ | K | K² | K Δ φ |
|---|---|---|---|---|---|---|---|---|---|
| | " | | | | | " | | | |
| May 10 | —0·23 | 0·0 | 0·00 | 0·00 | May 21 | +0·43 | +0·3 | 0·09 | +0·13 |
| 11 | —0·03 | +0·1 | 0·01 | 0·00 | 29 | —0·03 | 0·4 | 0·16 | —0·01 |
| 12 | —0·89 | 0·1 | 0·01 | —0·09 | 30 | 0·10 | 0·4 | 0·16 | +0·04 |
| 13 | —0·30 | 0·1 | 0·01 | —0·03 | 31 | +0·18 | 0·4 | 0.16 | +0·07 |
| 16 | —0·05 | 0·2 | 0·04 | —0·01 | June 1 | —0·02 | 0·5 | 0·25 | —0·01 |
| 18 | +0·02 | 0·2 | 0·04 | 0·00 | 2 | —0·60 | 0·5 | 0·25 | —0·03 |
| 20 | +0·18 | 0·2 | 0·04 | +0·04 | Sums | —1·24 | +3·4 | 1·22 | +0·10 |

$$[\Delta\varphi] = -1{\cdot}39 \qquad n = 62$$
$$[K] = +2{\cdot}9 \qquad [K]^2 = 8{\cdot}41$$
$$[KK] = +21{\cdot}99 \qquad [K]\,[\Delta\varphi] = -4{\cdot}03$$
$$[K\Delta\varphi] = +3{\cdot}35$$

From the preceding values the equation in $x$ corresponding to (2) is—

$$+21{\cdot}85\,x = +3''{\cdot}41$$

Formed in the same manner are the following equations, which are deduced from all the observations in groups I to VIII inclusive:

EQUATIONS IN $x$.

| GROUPS. | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | I. | | | II. | | | III. | |
| *Pair.* | + | " | *Pair.* | + | " | *Pair.* | + | " |
| 1 | 21·85 $x$ = | +3·41 | $1_1$ | 14·84 $x$ = | −0·19 | 1 | 9·03 $x$ = | +2·58 |
| 2 | 30·39 | −4·46 | $1_2$ | 21·32 | −2·72 | 2 | 9·65 | −2·46 |
| 3 | 27·07 | −0·27 | 2 | 30·27 | −0·45 | $3_1$ | 0·05 | −0·08 |
| 4 | 12·82 | −0·13 | $3_1$ | 30·94 | −3·16 | $3_2$ | 8·40 | +1·08 |
| 5 | 29·03 | −7·36 | $3_2$ | 33·94 | −3·68 | 4 | 8·44 | −2·53 |
| 6 | 12·80 | +5·22 | 4 | 36·33 | +0·21 | $5_1$ | 9·83 | −0·84 |
| 7 | 21·90 | −0·99 | $4_2$ | 2·18 | −0·59 | $5_2$ | 9·42 | −0·95 |
| $6_2$ | 3·87 | −0·18 | 5 | 37·09 | +2·37 | 6 | 10·11 | −0·06 |
| $7_1$ | 3·09 | −0·42 | 6 | 38·86 | −0·05 | 7 | 7·95 | −1·95 |
| $7_2$ | 3·09 | −0·65 | 7 | 36·87 | +1·45 | $8_1$ | 4·07 | +0·05 |
| $7_4$ | 8·72 | +0·46 | $8_1$ | 34·09 | +1·58 | $8_2$ | 4·12 | −1·77 |
| $7_5$ | 8·68 | −1·11 | $8_2$ | 33·47 | +0·87 | 9 | 8·01 | −2·41 |
| 8 | 17·56 | +3·84 | $9_1$ | 30·26 | +4·03 | 10 | 4·27 | −3·26 |
| 9 | 14·08 | +3·04 | $9_2$ | 32·14 | +1·34 | 11 | 6·09 | −2·31 |
| 10 | 22·26 | −4·17 | 10 | 25·81 | +0·73 | 12 | 8·66 | +1·53 |
| 11 | 15·92 | −2·65 | 11 | 31·08 | +1·76 | 13 | 7·15 | +0·16 |
| $11_2$ | 6·21 | −0·29 | $11_2$ | 19·49 | +2·26 | $14_1$ | 5·46 | −0·21 |
| $11_3$ | 5·67 | +0·48 | $11_3$ | 0·15 | −0·27 | $14_2$ | 0·01 | −0·05 |
| $11_4$ | 5·97 | +0·38 | $11_4$ | 0·10 | +0·04 | | | |
| 12 | 18·52 | +1·33 | $12_1$ | 11·81 | −0·52 | | | |
| $12_2$ | 4·98 | −0·54 | $12_2$ | 29·39 | +2·98 | | | |
| 13 | 18·58 | −2·05 | 13 | 29·00 | +0·47 | | | |
| $13_2$ | 4·77 | −0·06 | $14_1$ | 11·34 | −0·78 | | | |
| 14 | 21·70 | +0·88 | $14_2$ | 25·50 | +1·67 | | | |
| Σ | 339·5 | −6·29 | | 596·3 | +9·35 | | 120·7 | −13·48 |

## EQUATIONS IN $x$.—Continued.

| Groups. | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| IV. | | | V. | | | VI. | | |
| *Pair.* | + | " | *Pair.* | + | " | *Pair.* | + | " |
| 1 | 3·49 $x$ = | +2·35 | 1 | 1·73 $x$ = | −0·50 | $1_1$ | 1·25 $x$ = | −0·61 |
| 2 | 3·77 | −0·84 | 2 | 2·13 | +0·97 | $1_2$ | 0·00 | 0·00 |
| $3_1$ | 3·22 | −1·20 | 3 | 2·37 | +0·65 | $2_1$ | 0·33 | +0·24 |
| $3_2$ | 5·90 | −0·64 | 4 | 2·48 | +0·23 | $2_2$ | 1·29 | +0·60 |
| $4_1$ | 2·60 | +0·90 | 5 | 2·60 | −1·63 | 3 | 1·28 | +1·07 |
| $4_2$ | 2·70 | +0·33 | $6_1$ | 1·30 | −1·29 | 4 | 1·14 | −0·51 |
| 5 | 3·46 | −0·65 | $6_2$ | 0·43 | −1·03 | $5_1$ | 0·24 | −0·05 |
| 6 | 2·16 | +1·43 | 7 | 2·28 | +0·86 | $5_2$ | 1·20 | +0·86 |
| 7 | 3·11 | −0·32 | 8 | 1·67 | −0·26 | 6 | 1·09 | −1·49 |
| 8 | 2·43 | +1·36 | $9_1$ | 2·13 | −0·45 | $7_1$ | 1·21 | −0·22 |
| $9_1$ | 2·51 | −2·34 | $9_2$ | 1·54 | −0·36 | $7_2$ | 0·17 | +0·24 |
| $9_2$ | 2·46 | −1·98 | 10 | 1·76 | +0·65 | $8_a$ | 0·00 | +0·01 |
| 10 | 2·62 | −0·83 | 11 | 2·02 | −0·72 | $8_b$ | 0·93 | +0·96 |
| 11 | 1·77 | +0·76 | 12 | 1·40 | +0·28 | 9 | 0·86 | −0·49 |
| 12 | 1·60 | −0·08 | 13 | 1·52 | −0·88 | 10 | 0·94 | −0.22 |
| 13 | 0·95 | −0·30 | 14 | 1·28 | −0·35 | 11 | 2·40 | −0·65 |
| 14 | 1·35 | +0·04 | 15 | 1·41 | −0·98 | $12_1$ | 0·65 | −0·22 |
| | | | 16 | 1·28 | −0·98 | $12_2$ | 0·67 | +0·85 |
| | | | $17_1$ | 0·29 | +0·09 | $13_1$ | 0·19 | −0·17 |
| | | | $17_2$ | 0·75 | −0·21 | $13_2$ | 0·23 | −0·07 |
| | | | 18 | 0·92 | +0·08 | 14 | 0·14 | −0·16 |
| | | | | | | $15_1$ | 0·84 | −0·15 |
| | | | | | | $15_2$ | 0·99 | +0·41 |
| | | | | | | 16 | 0·63 | −1·38 |
| | | | | | | 17 | 0·31 | −0·24 |
| | | | | | | $18_1$ | 0·36 | +0·35 |
| | | | | | | $18_2$ | 0·01 | +0·03 |
| Σ | 46·10 | −2·01 | | 33·29 | −5·83 | | 19·35 | −1·01 |

EQUATIONS IN $x$.—CONTINUED.

| Groups. | | | | | |
|---|---|---|---|---|---|
| VII. | | | VIII. | | |
| *Pair.* | + | ″ | *Pair.* | + | ″ |
| 1 | 1·19 $x$ | = −0·71 | 1 | 8·38 $x$ | = −0·23 |
| $1_2$ | 1·06 | −0·39 | 2 | 9·64 | +3·17 |
| $2_1$ | 1·30 | −0·58 | 3 | 3·64 | −0·37 |
| $2_2$ | 1·17 | −1·13 | 4 | 4·80 | −0·22 |
| $2_3$ | 0·46 | +0·19 | 5 | 4·14 | +0·59 |
| $2_4$ | 0·36 | +0·04 | 6 | 4·59 | −0·45 |
| 3 | 1·51 | −0·72 | 7 | 4·89 | +0·39 |
| 4 | 1·97 | −0·67 | 8 | 3·84 | −0·31 |
| $5_1$ | 1·41 | +0·15 | 9 | 5·92 | −1·60 |
| $5_2$ | 1·50 | −0·52 | $10_1$ | 2·36 | −1·29 |
| 6 | 1·21 | −0·32 | $10_2$ | 2·76 | −1·32 |
| 7 | 1·42 | −0·05 | $11_1$ | 6·35 | +0·22 |
| $8_1$ | 1·48 | −0·04 | $11_2$ | 6·14 | −0·39 |
| $8_2$ | 1·35 | −0·41 | 12 | 4·00 | −0·23 |
| 9 | 1·19 | −0·12 | 13 | 5·43 | +1·05 |
| $10_1$ | 1·40 | +0·05 | $14_1$ | 2·02 | −0·06 |
| $10_2$ | 1·33 | −0·22 | $14_2$ | 4·79 | −0·10 |
| $10_3$ | 0·43 | −0·27 | 15 | 5·39 | −0·66 |
| $11_1$ | 1·35 | +0·19 | | | |
| $11_2$ | 1·37 | −0·22 | | | |
| $11_3$ | 0·43 | −0·24 | | | |
| $12_1$ | 1·06 | −0·19 | | | |
| $12_2$ | 3·00 | −0·57 | | | |
| 13 | 1·15 | −0·35 | | | |
| 14 | 0·19 | −0·46 | | | |
| 15 | 1·06 | −0·23 | | | |
| 16 | 0·54 | −0·08 | | | |
| Σ | 31·89 | −7·87 | | 89·08 | −1·81 |

The value of $x$ from Group I would therefore be:—

$$x = \frac{-6{\cdot}29}{339{\cdot}5} = -0{\cdot}0185,$$

and the correction to the constant of aberration from this group is $+ 1{\cdot}64 \times 0{\cdot}0185 = + 0{\cdot}030$, from which the value sought is $20''{\cdot}445 + 0{\cdot}030 = 20''{\cdot}475$

The following summary gives the equations in $x$ for each group, the resulting values of $x$, the number of observations, and the final corrections:

SUMMARY OF EQUATIONS IN $x$.

| GROUP. | EQUATIONS. | $x$ | $n$ | $1{\cdot}64\,x$. |
|---|---|---|---|---|
| | ″ | ″ | | ″ |
| I | $339.5\,x = -\ 6{\cdot}29$ | $-0{\cdot}0185$ | 1202 | $-0{\cdot}030$ |
| II | $596{\cdot}3\,x = +\ 9{\cdot}35$ | $+0{\cdot}0157$ | 1399 | $+0{\cdot}026$ |
| III | $120{\cdot}7\,x = -\ 13{\cdot}48$ | $-0{\cdot}1117$ | 720 | $-0{\cdot}183$ |
| IV | $46{\cdot}1\,x = -\ 2{\cdot}01$ | $-0{\cdot}0436$ | 497 | $-0{\cdot}072$ |
| V | $33{\cdot}3\,x = -\ 5{\cdot}83$ | $-0{\cdot}1751$ | 682 | $-0{\cdot}286$ |
| VI | $19{\cdot}4\,x = -\ 1{\cdot}01$ | $-0{\cdot}0517$ | 811 | $-0{\cdot}085$ |
| VII | $31{\cdot}9\,x = -\ 7{\cdot}87$ | $-0{\cdot}2468$ | 788 | $-0{\cdot}404$ |
| VIII | $89{\cdot}1\,x = -\ 1{\cdot}81$ | $-0{\cdot}0203$ | 669 | $-0{\cdot}033$ |
| | $1276{\cdot}3\,x = -\ 28{\cdot}95$ | $-0{\cdot}0227$ | 6768 | $-0{\cdot}037$ |

Constant of aberration $= 20''{\cdot}445 + 0''{\cdot}037 = 20''{\cdot}482$

VALUES OF ABERRATION CONSTANT FROM GROUPS.

| Group. | Constant. |
|---|---|
| | ″ |
| I | 20·475 |
| II | ·419 |
| III | ·628 |
| IV | ·517 |
| V | ·731 |
| VI | ·530 |
| VII | ·849 |
| VIII | ·478 |

These values, weighted with the coefficients of $x$ above, give the same value, viz: Constant of aberration $= 20''{\cdot}482$

PROBABLE ERROR.

The probable error of this result is estimated in the following way: The values of $C$, the corrections to the assumed declinations,

were calculated for each pair through two representative groups. These values and the values of $x$ substituted in all the conditional equations of the groups chosen, gave residuals from which the mean error of observation was calculated. The number of equations being represented by $m$ and the number of unknown quantities determined being equal to $\mu$, the mean error of observation is—

$$e = \sqrt{\frac{[\nu\nu]}{m-\mu}}$$

In the present case the average value of $e$ from the two groups, involving 51 pairs and 2 013 observations, was $\pm$ 0''·389.

The normal equations were then solved for each pair in order to get the weight of the unknown quantity $x$. These normal equations were—

$$n\,C + [K]\,x = 0$$
$$[K]\,C + [K\,K]\,x = 1$$

from which $x$ is equal to the reciprocal of the quantity—

$$[K^2] - \frac{[K]^2}{n}$$

This last written value is, therefore, the weight of $x$, or $p_x$, and the mean error of $x$ from each pair would be found by dividing the mean error of observation by $\sqrt{p_x}$

An average value for the 51 pairs, of the mean error of $x$ from 1 pair, gave 0''·395. The probable error is, therefore, 0·6745 × 0''·395 = 0''·266. The value of $x$ as derived from the conditional equation must be multiplied by 1·64 in order to get the correction to the aberration constant. Hence the probable error of this correction from one pair of stars may be taken as 0''·436, and the probable error of the result depending on 176 pairs would be—

$$\frac{0''.436}{\sqrt{176}} = \frac{0''.436}{13.3} = 0''.033$$

This is on the assumption that the average mean error for 51 pairs is the same as the average for 176 pairs, a supposition which seems to be justified within reasonable limits by the range of the values calculated.

The constant of aberration from the San Francisco observations may then be given as—

$$20''.482 \pm 0''.033$$

TREASURY DEPARTMENT,
UNITED STATES COAST AND GEODETIC SURVEY.
W. W. DUFFIELD,
SUPERINTENDENT.

---

BULLETIN NO. 33.

---

# THE DIRECTION AND INTENSITY

OF THE

## EARTH'S MAGNETIC FORCE

AT

## SAN FRANCISCO, CALIFORNIA.

---

A report by CHAS. A. SCHOTT, ASSISTANT.
Submitted for publication December 4, 1894.

---

Bulletins are issued by the Survey from time to time as material for them accumulates. They are intended to give early announcement of work accomplished or information of importance obtained, and will in many cases anticipate the usual means of publication afforded by the Annual Reports. Those already published, Nos. 1 to 25 inclusive, in quarto form, have their pages numbered consecutively and constitute Vol. I. No. 26 begins Vol. II, which will be published in octavo.

---

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1895.

# THE DIRECTION AND INTENSITY OF THE EARTH'S MAGNETIC FORCE AT SAN FRANCISCO, CAL.

CHAS. A. SCHOTT, ASSISTANT.

The magnetic station at San Francisco may be regarded as a representative one for the Western Coast, both in regard to central position and to fullness of material for the discussion of the changes which the magnetic force undergoes in the course of time. The study of these changes with a view of elucidating the laws which apparently govern them, must therefore be renewed from time to time, since all expressions yet constructed are necessarily empirical in their character.

(1). In a region where the secular changes in the declination, the inclination, and the intensity of the force, is so little understood as in the States of California, Oregon, and Washington, it becomes imperative to watch every indication pointing to an improvement in their expression, and the present inquiry has its origin in the fact, that between the years 1882 and 1889 there was a strong indication of a maximum value of the declination having been attained. The prediction of 1893 for this epoch,* with a declination of $16^{\circ}\cdot 6$ East, appeared to be sustained until the results from accumulated observations made yearly by direction of Assistant G. Davidson, between 1890 and the present time, showed a decided annual increase of fully $1'\cdot 5$. For the reconstruction of the analytical formula of 1886, there are now available 32 values of the declination between 1783 and 1894, and it may be remarked that it is impracticable to make any use of the earliest observation we have on this coast † (Sir Francis Drake 1579, the Arcano del Mare 1646, G. F. G. Carreri 1693) by reason of the long interval during which our present information is a complete blank. In the first quarter of the 17th century the declination at San Francisco was probably not far from 8° East.‡

The new expression for the secular variation is as follows:

$$D = -13^{\circ}\cdot 73 + 2\cdot 94 \sin (0\cdot 95\, m - 135^{\circ}\cdot 3) + 0\cdot 056 \sin (20\, m + 87^{\circ})$$

where $D$ = the declination for any year $Y$, and $m = Y - 1850\cdot 0$; the second periodic term (having a period of 18 years) applies only after 1872, and was introduced to serve temporarily and until a

* Appendix No. 12—Report for 1886, p. 400.

† Appendix No. 7—Report for 1888, p. 279.

‡ U. S. C. and G. Survey Bulletin No. 5, May, 1888.

firmer grasp can be had of this secondary wave, should it exist; the term may generally be omitted. The first periodic term of a period of 379 years places the maximum late in the year 1897, and gives its amount as— 16°·7. For further developments, continued observations at this place will be of special value and interest.

The formula (omitting second periodic term) represents the observed values * as follows:

| No. | Year. | Obs'd $D$ | Comp'd $D$ | $C-O$ |
|---|---|---|---|---|
| | | ° | ° | ° |
| 1 | 1783·3 | — 12·91 | — 12·81 | +0·10 |
| 2 | 92·9 | 12·80 | 13·27 | — 0·47 |
| 3 | 1818·7 | 15·00 | 14·50 | + 0·50 |
| 4 | 27·5 | 15·45 | 14·90 | + 0·55 |
| 5 | 29·9 | 14·92 | 15·01 | — 0·09 |
| 6 | 30·5 | 14·85 | 15·03 | — 0·18 |
| 7 | 37·5 | 15·17 | 15·33 | — 0·16 |
| 8 | 39·5 | 15·33 | 15·41 | — 0·08 |
| 9 | 41·9 | 15·50 | 15·50 | 0·00 |
| 10 | 50·0 | 15·68 | 15·80 | — 0·12 |
| 11 | 52 3 | 15·48 | 15·88 | — 0·40 |
| 12 | 58·4 | 15·88 | 16·07 | — 0·19 |
| 13 | 66·5 | 16·42 | ·28 | + 0·14 |
| 14 | 71·9 | ·38 | ·41 | — 0·03 |
| 15 | 72·8 | ·43 | ·42 | + 0·01 |
| 16 | 73·7 | ·41 | ·44 | — 0·03 |
| 17 | 74·0 | ·45 | ·45 | 0·00 |
| 18 | 79·2 | ·57 | ·53 | + 0·04 |
| 19 | 80·8 | ·56 | ·56 | 0·00 |
| 20 | 81·5 | ·48 | ·56 | — 0·08 |
| 21 | 83·4 | ·64 | ·59 | + 0·05 |
| 22 | 84·7 | ·54 | ·60 | — 0·06 |
| 23 | 85·6 | ·56 | ·61 | — 0·05 |
| 24 | 86·3 | ·55 | ·62 | — 0·07 |
| 25 | 87·9 | ·56 | ·63 | — 0·07 |
| 26 | 88·4 | ·57 | ·63 | — 0·06 |
| 27 | 89·3 | ·60 | ·64 | — 0·04 |
| 28 | 90·8 | ·64 | ·65 | — 0·01 |
| 29 | 91·7 | ·66 | ·66 | 0·00 |
| 30 | 92·8 | ·67 | ·66 | + 0·01 |
| 31 | 93·6 | ·69 | ·66 | + 0·03 |
| 32 | 1894·8 | — 16·74 | — 16·67 | + 0·07 |

The probable error of any one representation is ± 10′.

(2). Respecting the secular variation of the inclination, when writing Appendix No. 6, Report of 1885, I concluded that on this

* ndix No. 7—Report for 1888, pp. 277-278.

coast the dip was then either stationary or subject to but slight annual change (supposed decrease). Our present information on this point is still extremely meager, yet the more recent observations indicate apparently a small annual *increase* of dip, probably operative since about the year 1865, or earlier, and observations at San Diego, Los Angeles and Monterey seem to support this view. The earliest dip observation at this place ** bears the date 1815, November 1, and is by the Russian navigator Kotzebue; the latest is of 1894, November 1.

It is, however, not possible to discern a law that would represent the change in the dip during these seventy-nine years. This is due to the fact that the observing errors exceed in magnitude and hide the small changes due to the secular variation. The change since 1865 is all that can be given and is represented by the simple expression

$$\theta = 62^{\circ}.39 + 0.009\ (t - 1885.7)$$

where $t$ is any year between 1865 and say 1900.

Increasing dip is in accordance with the clockwise motion in the secular curve of the direction of the total force.

The following table contains the observed dips up to date:

| Year. | Dip. | Year. | Dip. | Year. | Dip. |
|---|---|---|---|---|---|
| | ° | | ° | | ° |
| 1815·8 | 62·77 | 1873·9 | 62·08 | 1888·4 | 62·39 |
| 31·1 | 62·97 | 80·7 | ·32 | 89·3 | ·40 |
| 37·5 | 61·90 | 81·5 | ·42 | 90·8 | ·48 |
| 39·5 | 62·10 | 82·3 | ·42 | 91·7 | ·50 |
| 52·1 | 62·35 | 84·7 | ·34 | 92·8 | ·47 |
| 58·4 | 62·78 | 86·3 | ·28 | 93·6 | ·50 |
| 1866·5 | 62·37 | 1887·9 | 62·42 | 1894·8 | 62·48 |

(3) The dates of the measure of the horizontal component of the earth's magnetic force are comparatively quite recent. As is well known, Gauss, in 1833, showed how this force could be expressed in absolute terms, and Weber's portable magnetometer of 1836 gave the means of doing it; certain relative measures made before this date could be utilized, though their value in absolute measure was small. Of the latter description are the values for the total force* $F = 0.5533$ of a dyne, deduced from observations made in 1829 by Erman, and the value for the horizontal component $H = 0.2534$ of a dyne for 1831, February, derived from a record mentioned by

** Appendix No. 6—Report for 1885, pp. 144–145.

*Appendix No. 6—Report for 1885, pp. 144-45.

Douglas. It was already known in 1885 that the total force, as well as its horizontal component, were slowly diminishing in value since about the year 1860. This is now confirmed, as will be seen from the following records and statements:

OBSERVED VALUES OF THE HORIZONTAL COMPONENT $H$ (IN DYNES.)

| No. | Year. | $H$. | No. | Year. | $H$. |
|---|---|---|---|---|---|
| 1 | 1831·1 | 0·2534 | 11 | 1885·6 | 0·2530 |
| 2 | 1839·5 | 0·2547 | 12 | 1886·3 | 0·2529 |
| 3 | 1858·4 | 0·2571 | 13 | 1887·9 | 0·2529 |
| 4 | 1866·5 | 0·2602 | 14 | 1888·4 | 0·2528 |
| 5 | 1873·9 | 0·2556 | 15 | 1889·3 | 0·2526 |
| 6 | 1880·7 | 0·2542 | 16 | 1890·8 | 0·2533 |
| 7 | 1881·5 | 0·2541 | 17 | 1891·7 | 0·2520 |
| 8 | 1882·3 | 0·2550 | 18 | 1892·8 | 0·2517 |
| 9 | 1883·4 | 0·2527 | 19 | 1893·6 | 0·2514 |
| 10 | 1884·7 | 0·2529 | 20 | 1894·8 | 0·2514 |

These observed values can be well represented by a formula of the form

$$H = H_0 + y\,(t - 1850{\cdot}0) + z\,(t - 1850.0)^2.$$

We find :

$$H = 0{\cdot}2569 + 0{\cdot}000\,153\,(t - 1850{\cdot}0) \\ - 0{\cdot}000\,006\,685\,(t - 1850{\cdot}0)^2.$$

For the time of maximum we have : $t = 1850 - \frac{y}{2z} = 1861{\cdot}46$ for which $H = 0{\cdot}2578$ ; the value of $H$ for 1895 is $0{\cdot}2502$, and the annual change $\frac{dH}{dt} = y + 2z\,(t - 1850{\cdot}0)$ becomes for 1895, $-0{\cdot}000\,448$ of a dyne or in parts of the force, $\frac{dH}{H} = -0{\cdot}001\,791 = -\frac{1}{558.2}$ of the force.

We also have for 1895.0 with $H = 0{\cdot}2502$ and $\theta = 62^\circ{\cdot}47$ the total force $F = H$ sec. $\theta = 0{\cdot}5414$, also the vertical force

$$V = H \tan \theta = 0{\cdot}4801;$$

the annual change of $F$ is given by

$$dF = \sec.\,\theta\, d\,H + F \tan \theta\, d\,\theta = -0{\cdot}000\,805$$

and when expressed in parts of the force

$$\frac{dF}{F} = \frac{dH}{H} + \tan \theta\, d\,\theta = -0{\cdot}001\,49 = -\frac{1}{671{\cdot}1} \text{ of the force.}$$

The above discussion will be of assistance when examining into the changes going on at places in the vicinity of the Golden Gate.

TREASURY DEPARTMENT,

UNITED STATES COAST AND GEODETIC SURVEY.

W. W. DUFFIELD,

SUPERINTENDENT.

---

## BULLETIN No. 34.

# DISTRIBUTION

OF THE

# MAGNETIC DECLINATION IN ALASKA

AND

# ADJACENT WATERS FOR THE YEAR 1895,

WITH ONE CHART.

---

A report by C. A. SCHOTT, Assistant.

Submitted for publication December 19, 1894.

Bulletins are issued by the Survey from time to time as material for them accumulates. They are intended to give early announcement of work accomplished or information of importance obtained, and will in many cases anticipate the usual means of publication afforded by the Annual Reports. Those already published, Nos. 1 to 25, inclusive, in quarto form, have their pages numbered consecutively and constitute Vol. I. No. 26 begins Vol. II, which will be published in octavo.

---

WASHINGTON:

GOVERNMENT PRINTING OFFICE.

1895.

2—2248

# ABSTRACT OF REPORT ON THE DISTRIBUTION OF THE MAGNETIC DECLINATION IN ALASKA AND ADJACENT WATERS FOR THE YEAR 1895, AND CONSTRUCTION OF AN ISOGONIC CHART FOR THE SAME EPOCH.

C. A. SCHOTT, Assistant.

Five years have elapsed since the production by the Coast and Geodetic Survey of an isogonic chart covering the whole of Alaska Territory and adjacent regions, during which interval so much of new information has become available, either by discovery of old records or in the shape of new observations and recent discussions, that an entire reconstruction of the isogonic chart has become a necessity in order that the charts of this Territory and the approaches thereto may have their compass variations correctly indicated.

Prior to 1892 our knowledge of the annual change of the magnetic declination was very imperfect for the vast region comprising the coast of Alaska and still more for the interior. Since that time, however, observations made by the Coast and Geodetic Survey, especially those in connection with the survey of the boundary during the years 1889–'94, as well as information gathered from other sources, have aided greatly in assigning improved values to the annual change and in clearing up obscure cases and giving new information at certain points. In the higher latitudes the evaluation of the annual change presents special difficulties in consequence of the paucity of material and the comparatively large diurnal variation, which has to be allowed for in the resulting declination. In southeastern Alaska, and even as far south as the State of Washington, it was believed up to 1892 that the direction of the magnetic needle was either stationary or moving slightly westward; but observations made at Sitka in 1892, 1893, and 1894, at Fort Wrangell in 1893, and at Seattle and Tacoma in May, 1894, as well as a discussion of observation made at Esquimalt (Victoria), Vancouver Island, between 1858 and 1892, establish the fact of an increasing easterly declination for those stations and the adjacent regions. At Yakutat Bay, also, the survey of 1892 brought out the fact of a deflection of the needle of 47′ at Khantaak Island as compared with

other places on the bay; and demanded the cancellation of the annual change of $+8'\cdot 8$ given on the isogonic chart for 1890 and the substitution of the words, "annual change inappreciable." With respect to the interior of Alaska, the most important station where information was secured is Fort Yukon, where observation in 1889 and 1890 showed the declination to be decreasing a few minutes per annum, in entire accord with the easterly decline noticed to take place all along the shores washed by Bering Sea and the Arctic Ocean. The fortunate recovery of Bering's magnetic observations, made on his first voyage to the coasts of Kamchatka and eastern Asia in the years 1725 to 1730 and their discussion by me in December, 1890 (published in Bulletin No. 20, Dec. 12, 1890, and in Appendix No. 5, Report for 1891), greatly extended and improved our knowledge of the secular variation of the declination in that part of the world and modified the former values of the annual change at stations on the opposite or American coast.

The uncertainty of the value of the annual change in certain localities led to the adoption of the year 1895·0 as the epoch for a new isogonic chart, leaving future improvements to be made for a chart for the year 1900. Of the material on hand only the later observations were introduced, being less liable to error when reduced to the epoch; but for the reduction of these observed declinations to the adopted epoch, use was made of all information at present available in the general collection of magnetic observations on file in the Computing Division, resorting to interpolation in regions where only an approximate or no value for the annual change could be obtained. The lack, in that collection, of any late observations on the western part of Bering Sea and along the coast of eastern Siberia and Kamchatka rendered it undesirable to extend the investigation west of about 175° west longitude.

There are two ways of constructing isogonic curves—by means of a graphical and by means of an analytical process; but the former is here out of the question by reason of the large geographical extent involved and the scarcity and irregularity of distribution of the observations. By the analytical method, adopted in this case, the declination ($D$) (reduced to epoch) at any place within the spherical surface under consideration may be expressed as a function of the latitude ($\varphi$) and longitude ($\lambda$). The function adopted is the same in form and number of terms as that used by me in the preceding investigation in 1889, and is as follows:

$$D = D_0 + r\,\Delta\varphi + s\,\Delta\lambda \cos\varphi + t\,\Delta\varphi^2 + u\,\Delta\varphi\Delta\lambda\cos\varphi + v\Delta\lambda^2\cos^2\varphi$$
$$+ w\,\Delta\varphi^3 + x\,\Delta\varphi^2\Delta\lambda\cos\varphi + y\,\Delta\varphi\Delta\lambda^2\cos^2\varphi + z\,\Delta\lambda^3\cos^3\varphi$$

where $\Delta\varphi = \varphi - \varphi_0$, $\Delta\lambda = \lambda - \lambda_0$, and $r, s, t, u, v, w, x, y, z$ represent unknown numerical coefficients to be determined from the observations themselves. The values of $\varphi_0$ and $\lambda_0$ represent the average

latitude and the average longitude, respectively, of the magnetic stations, and $D_0$ is the value of the declination corresponding to that average position. For $D_0$ we take the approximate value $D_1$ and find the correction $q$ to it, so that $D_0 = D_1 + q$. Applying the method of least squares to the problem, the observation equations take the form

$$o = D_1 - D + q + \varphi_{,} r + \lambda_{,} \cos \varphi \, s + \varphi_{,}^2 t + \varphi_{,} \lambda_{,} \cos \varphi \, u + \lambda_{,}^2 \cos^2 \varphi \, v$$
$$+ \varphi_{,}^3 w + \varphi_{,}^2 \lambda_{,} \cos \varphi \, x + \varphi_{,} \lambda_{,}^2 \cos^2 \varphi \, y - \lambda_{,}^3 \cos^3 \varphi \, z$$

where for shortness we write $\varphi_{,}$ for $\Delta\varphi$ and $\lambda_{,}$ for $\Delta\lambda$. Of these equations there would be as many as there are observations; but as any large number would be either cumbersome or unmanageable, the observations need to be contracted into mean values of groups or so-called normals. A group may consist of any number of places of observation located near enough together to be united into a mean.

In the present discussion there are 131 stations involved and they are collected into 39 groups of from 1 to 15 stations, the mean values from the different groups being taken as of equal weight. The following table gives these mean values, with the number of stations included and the adopted annual change. As usual on the Survey, east declination is indicated by a minus sign prefixed, and the same sign is given an annual *increase* of east declination.

*Recapitulation of standard values of magnetic declinations in Alaska and adjacent parts, for January, 1895.*

| No. of Group. | Designation of Group. | Number of Stations. | Latitude. | Longitude. | Annual change. | D 1895·0. | D Computed | C—O. |
|---|---|---|---|---|---|---|---|---|
| | | | ° | ° | ′ | ° | ° | ° |
| I | Puget Sound | 2 | 47·44 | 122·39 | —2 | —22·62 | —22·49 | +0·13 |
| II | Strait of Juan de Fuca | 10 | 48·37 | 123·16 | —2·5 | —23·33 | —23·18 | +0·15 |
| III | Cape Flattery | 9 | 48·54 | 124·74 | —2 | —23·75 | —23·47 | +0·28 |
| IV | Nootka and Quatsino Sounds | 2 | 50·04 | 127·34 | —1·5 | —24·58 | —24·62 | —0·04 |
| V | Thompson River | 10 | 50·68 | 120·72 | —1 | —24·78 | —24·65 | +0·13 |
| VI | Great Fork, Frazer River | 4 | 52·96 | 119·91 | —1 | —26·34 | —26·83 | —0·49 |
| VII | Queen Charlotte Island | 1 | 52·15 | 131·25 | —1·5 | —26·34 | —26·01 | +0·33 |
| VIII | At Sea, Northeast Pacific Ocean* | 3 | 45·00 | 135·00 | ? | —21·75 | —22·04 | —0·29 |
| IX | At Sea, Northeast Pacific Ocean* | 1 | 45·00 | 128·50 | ? | —21·75 | —22·04 | —0·29 |
| X | At Sea, Northeast Pacific Ocean* | 3 | 47·00 | 155·00 | ? | —19·75 | —19·57 | +0·18 |
| XI | At Sea, Northeast Pacific Ocean* | 4 | 51·00 | 145·00 | ? | —23·80 | —23·13 | +0·67 |
| XII | Port Simpson and Skeena River | 8 | 54·54 | 129·96 | —2 | —27·73 | —28·09 | —0·36 |
| XIII | Fort Wrangell | 15 | 56·01 | 132·55 | —1·9 | —29·47 | —29·00 | +0·47 |
| XIV | Sitka | 1 | 57·05 | 135·34 | —2 | —29·63 | —29·29 | +0·34 |
| XV | Lynn Canal and vicinity | 6 | 58·54 | 134·96 | —1·5 | —30·56 | —30·77 | —0·21 |
| XVI | Yakutat Bay | 5 | 59·63 | 139·85 | ? | —30·32 | —30·18 | +0·14 |
| XVII | Vicinity of Mount Lorne | 4 | 60·73 | 135·13 | +1 | —32·35 | —32·96 | —0·61 |
| XVIII | Port Etches | 1 | 60·35 | 146·63 | +3 | —27·88 | —28·09 | —0·21 |
| XIX | Cook Inlet | 2 | 59·50 | 151·64 | +4 | —24·52 | —25·41 | —0·89 |
| XX | Kadiak Island | 1 | 57·80 | 152·36 | +4 | —24·18 | —24·22 | —0·04 |
| XXI | Semidi Islands | 3 | 56·07 | 156·92 | +4 | —21·30 | —21·84 | —0·54 |
| XXII | Shumagin Islands | 6 | 55·40 | 160·61 | +4 | —20·15 | —20·34 | —0·19 |
| XXIII | Unalaska Island | 1 | 53·88 | 166·52 | +3 | —18·07 | —18·14 | —0·07 |
| XXIV | Pribilof Island | 1 | 57·12 | 170·32 | +3·6 | —16·81 | —16·96 | —0·15 |
| XXV | Hagmeister Island | 1 | 58·80 | 160·83 | +4·5 | —21·35 | —21·16 | +0·19 |
| XXVI | Nunivak Island | 1 | 60·42 | 166·13 | +5 | —19·86 | —19·21 | +0·65 |
| XXVII | Vicinity of Upper Ramparts, Yukon River. | 4 | 63·44 | 139·26 | +2 | —34·16 | —34·21 | —0·05 |
| XXVIII | Vicinity of Boundary Mountain, Yukon River. | 2 | 64·69 | 140·93 | +3 | —35·48 | —34·81 | +0·67 |
| XXIX | St. Michael | 1 | 63·48 | 162·09 | +6·5 | —22·66 | —22·57 | +0·09 |
| XXX | Port Clarence | 1 | 65·27 | 166·83 | +7·3 | —21·14 | —20·93 | +0·21 |
| XXXI | Kotzebue Sound | 1 | 66·22 | 161·82 | +7·1 | —25·13 | —24·60 | +0·53 |
| XXXII | Cape Lisburne and vicinity | 2 | 68·60 | 166·41 | +8·5 | —23·04 | —23·84 | —0·80 |
| XXXIII | Icy Cape and vicinity | 6 | 70·24 | 161·80 | +9·5 | —29·22 | —28·78 | +0·44 |
| XXXIV | Fort Yukon | 1 | 66·56 | 145·30 | +4·4 | —34·88 | —34·65 | +0·23 |
| XXXV | Porcupine River at Boundary | 1 | 67·42 | 140·98 | +6 | —37·66 | —38·16 | —0·50 |
| XXXVI | Valley of Three Rivers | 1 | 68·61 | 141·00 | +8 | —39·92 | —39·77 | +0·15 |
| XXXVII | Firth River | 2 | 69·47 | 139·48 | +10 | —42·68 | —41·92 | +0·76 |
| XXXVIII | Cross Island | 1 | 70·46 | 147·88 | +12 | —37·59 | —38·19 | —0·60 |
| XXXIX | Point Barrow | 3 | 71·31 | 156·52 | +12 | —33·50 | —33·78 | —0·28 |

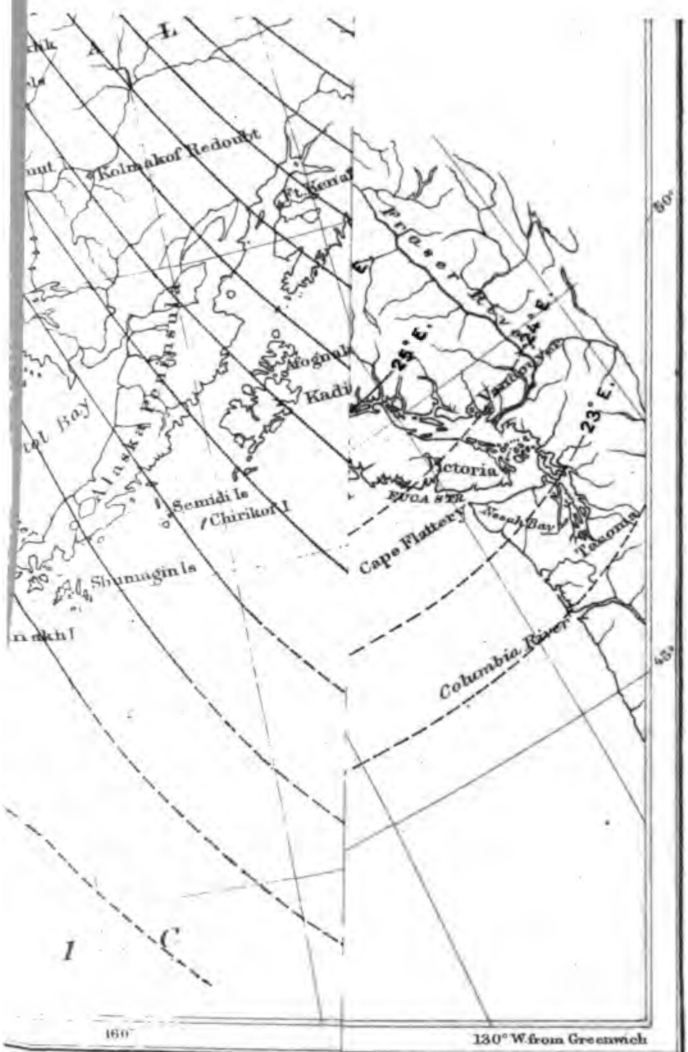
*By interpolation, using the isogonic curves of 1890, values uncertain.

The approximate central value of latitude used is $\varphi_0 = 59^\circ{\cdot}02$ and of longitude $\lambda_0 = 145^\circ{\cdot}12$, and $D_1$ is assumed $= -27^\circ{\cdot}16$. With these values were formed 39 observation equations, and the solution of the resulting 10 normal equations gave the following expression for the distribution of the magnetic declination in and about Alaska for the epoch 1895·0:

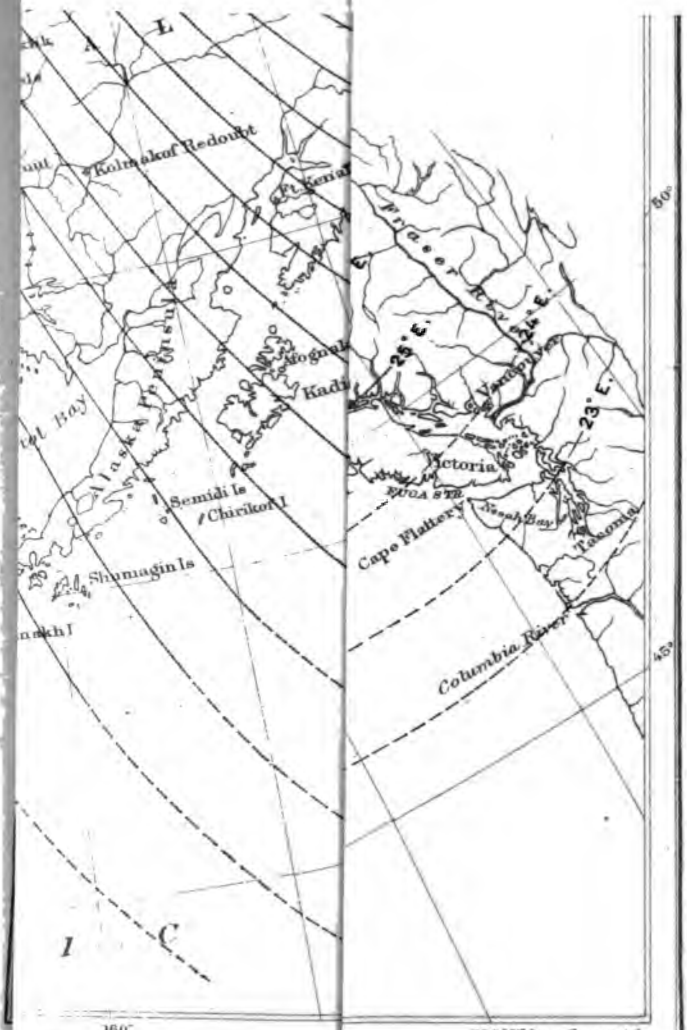
$$\begin{aligned} D = &-27^\circ{\cdot}7288 - 0{\cdot}71688\,\varphi_{,} + 0{\cdot}73731\,\lambda_{,}\cos\varphi \\ &- 0{\cdot}023982\,\varphi_{,}^2 + 0{\cdot}070893\,\varphi_{,}\lambda_{,}\cos\varphi + 0{\cdot}010915\,\lambda_{,}^2\cos^2\varphi \\ &- 0{\cdot}0005744\,\varphi_{,}^3 + 0{\cdot}0025613\,\varphi_{,}^2\lambda_{,}\cos\varphi + 0{\cdot}0001956\,\varphi_{,}\lambda_{,}^2\cos^2\varphi \\ &- 0{\cdot}0003342\,\lambda_{,}^3\cos^3\varphi \end{aligned}$$

where $\varphi_{,} = \varphi - 59^\circ{\cdot}02$ and $\lambda_{,} = \lambda - 145^\circ{\cdot}12$. By means of this formula the declination was computed for each of the normal groups, and the differences between the observed and computed values $(C-O)$, given in the last column of the foregoing table, show the closeness with which the observed facts are represented, as well as the deviations from a regular distribution (as implied by the formula) of magnetism. These differences are made up of four distinct sources of error, viz: Errors of observation, errors in the reduction to epoch, errors due to imperfection or insufficiency of the analytical formula employed, and, lastly and chiefly, to irregularities in the local distribution of terrestrial magnetism, of which the general formula can not take cognizance. The probable error of a single representation becomes $r = \pm\, 0^\circ{\cdot}323$ or $\pm\, 19'$, an improvement on the value of $r = \pm\, 26'$ for the representation of 1890, and the largest discrepancies are reduced from $1^\circ{\cdot}6$ and $1^\circ{\cdot}2$ in 1890 to $0^\circ{\cdot}9$ and $0^\circ{\cdot}8$ in the present case.

For the construction of any desired isogonic curve we need a number of intersections with parallels or meridians sufficient to enable us to trace the curve by a free hand through these points. It is most convenient to accommodate the general expression for $D$ to a particular parallel and solve the resulting cubic equations to find the intersection with the meridian; but the computation and curves must be limited to the area roughly bounded by the normals. The accompanying chart of Alaska exhibits the isogonic curves for 1895 thus obtained, but modified somewhat near the limit of this investigation to accommodate them to the conditions existing outside that limit. They are drawn as broken lines in that part of the North Pacific adjacent to the Gulf of Alaska and in the western part of Bering Sea, where the uncertainty in the computed declination is greatest. This uncertainty may amount to half a degree, and is supposed not to exceed one degree about the southern limit of the curves. In this part of the North Pacific the want of recent and reliable observation is much felt.


Kolmakof Redoubt
Ft. Kenai
Alaska Peninsula
Semidi Is
Chirikof I
Shumagin Is
Kadi
Fraser
25° E.
24° E.
23° E.
Victoria
FUCA STR
Cape Flattery
Neah Bay
Tacoma
Columbia River
60°
45°
160°
130° W. from Greenwich

ER 1894


Kolmakof Redoubt
Ft Kenai
Fraser River
25° E.
24° E.
23° E.
Vancouver
Semidi Is
Chirikof I
Shumagin Is
Victoria
FUCA STR.
Cape Flattery
Neah Bay
Tacoma
Columbia River
50°
45°
160°
130° W. from Greenwich

BER 1894

TREASURY DEPARTMENT,

UNITED STATES COAST AND GEODETIC SURVEY,

W. W. DUFFIELD,

SUPERINTENDENT.

BULLETIN No. 35.

# ALASKA.

# GENERAL INFORMATION

RELATING TO

THE VICINITY OF CHATHAM AND PERIL STRAITS, FROM A RECENT SURVEY BY THE U. S. COAST SURVEY STEAMER PATTERSON, LIEUT. COMMANDER E. K. MOORE, U. S. N., COMMANDING,

AND

COOKS INLET AND THE REGION TO THE WESTWARD, BY W. H. DALL, U. S. GEOLOGICAL SURVEY.

Arranged and Compiled by HUGH RODMAN, Lieut. U. S. Navy,
Assistant, U. S. Coast and Geodetic Survey.

Bulletins are issued by the Survey from time to time as material for them accumulates. They are intended to give early announcement of work accomplished or information of importance obtained, and will in many cases anticipate the usual means of publication afforded by the Annual Reports. Those already published, Nos. 1 to 25 inclusive, in quarto form, have their pages numbered consecutively and constitute Vol. I. No. 26 begins Vol. II, which will be published in octavo.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1896.

# PREFACE.

The following information is compiled from a survey made in the summer of 1895 by the Coast Survey steamer *Patterson* in Chatham and Peril Straits, from Point Gardner to Killisnoo, thence through Peril Strait to Sergius Narrows, and from the notes of Prof. W. H. Dall, U. S. Geological Survey, made about the same time, in Cooks Inlet and to the westward.

It is very general in character, and that which relates to Chatham and Peril Straits is preliminary to the charts and sailing direction which will be published, covering the same ground, in the near future.

In the territory around Cooks Inlet the charts are far from correct, but they are compiled from the most reliable sources, and it is hoped that in time this part of Alaska may be accurately charted.

The sailing directions and notes are taken from the reports of Lieut. Commander E. K. Moore, U. S. N., commanding the Coast Survey steamer *Patterson*, and cover the ground from Point Gardner, at the junction of Frederick Sound and Chatham Strait, to Povorotni Island, in Peril Strait. These notes were compiled during the season of 1895, from May to October, and are a very valuable addition to the scant information already existing in print on this part of Alaska.

# COMPILATION OF THE MOST RECENT INFORMATION RELATIVE TO THE HARBORS, ANCHORAGES, AND DANGERS TO NAVIGATION IN THE VICINITY OF CHATHAM AND PERIL STRAITS AND COOKS INLET, ALASKA.

On the eastern shore of Chatham Strait the mountains are not so abrupt or rugged as on the western side. The tops are nearly all rounded and bare, with the exception of grass and light underbrush. Owing to the prevalence of snow slides no general rule can be given for the height of the timber line. The rest of the country is covered with a heavy growth of cedar, fir, spruce, maple, alder and blueberry bushes, greatly impeding travel. The highest peak on the eastern shore is between Cha-ik and Whitewater Bays, 3,241 feet, and is an irregular, solitary mountain with two principal peaks. On the southern shore of Whitewater Bay, and making a prominent landmark for it, is a mountain, 2,438 feet high, called Table Mountain, peculiarly eroded near the top. This is the only prominent peak between Whitewater Bay and Point Gardner, the country being composed of low, rolling hills, heavily timbered, lacking individuality, and containing no prominent features.

On the western shore, with the exception of the country between Point Thatcher and Point Lull, the country is much more rugged and broken, many of the peaks reaching altitudes of 4,000 feet, and apparently increasing in height to the southward. These peaks are nearly all bare and rocky and covered with snow until late in the summer, some of them perpetually. A few remnants of glaciers can be seen in some of the upper gulches. The timber line proper is much lower here than on the eastern side, and above it the underbrush is also much lighter. This is due probably to the later melting of the snow and the greater frequency of snow slides.

Chatham Strait, in the main, is a clear, honest sheet of water, most of the dangers to navigation lying well inshore, and generally inside of a line drawn from point to point. On the western shore from abreast Point Gardner to the southern point of Kelp Bay there are no outlying dangers, and the reefs in the small bights are nearly all visible at half tide. About two-thirds of a mile SE. ½ S. from Point Lull is a sunken rock, well marked by kelp, and from here to Point Thatcher the shore should not be approached within half a mile, as there are several reefs extending well offshore, and the bottom is very irregular

and foul. Although well marked by kelp, there may be some shoals undiscovered. Much of this kelp is attached to small rocks and bowlders, varying in size from a hen's egg to a brick, and under the influence of heavy seas or strong tidal currents a vessel is very liable to drag anchor.

On the western shore are three prominent waterfalls which make excellent landmarks. The first is 4 miles below the southern point of Kelp Bay, very high, and visible for a considerable distance to the northward, appearing as a white line or streak against the dark background of the hills. The second is a large but not particularly high waterfall at the head of Warm Spring Bay, which is visible from Chatham Strait for a short distance to the southward of the bay. The third is similar to the last in appearance, in an open bight which has received the local name of Cascade Bay. This waterfall is visible from vessels bound north in mid-channel up to a point one-half mile to the northward of a line drawn from Point Gardner at right angles to the general direction of the channel.

From Point Gardner to Point Wilson, the southern point of Wilson Cove, the shore is low, except in one place noted on the chart, with no reefs or dangers making off to any extent.

Wilson Cove, 8 miles above Point Gardner, is an open, shallow bight, about 1 mile deep, with a width at its entrance of 2 miles. At its head is an extensive flat. On its southern shore are two small wooded islands, the inner one being much higher and more heavily wooded of the two. In the entrance is an extensive reef, generally visible, but covered at the spring high waters, extending across the mouth for a distance of half a mile. The southern shore is very foul and rocky, and full of kelp, much of it being secured to small rocks and bowlders. On the northern shore are several caverns in the faces of the cliffs, which are from 75 to 100 feet in height. Wilson Cove should be avoided, as it affords no protection as an anchorage except from easterly winds, and is very foul, bottom showing in four or five fathoms in many places.

Point Caution, 14 miles above Point Gardner, and 5 miles above Wilson Cove, is the southern point of Whitewater Bay. Two and one-half miles south of it a shoal extends offshore one-third of a mile from a small wooded islet connected with the shore at low water. Otherwise the shore is free from dangers between Point Caution and Wilson Cove. Directly behind Point Caution is the mountain previously referred to as marking the entrance to Whitewater Bay.

One-sixth of a mile NW. from Point Caution is a low, rocky islet, bearing a single dead tree, from which it derives the name of Lone Tree Island.

One and three-quarter miles N. ½ W. from Point Caution is Woody Point, with a small rocky, wooded islet, one-third of a mile offshore. This is the northern point of Whitewater Bay.

Whitewater Bay extends in an easterly direction for a distance of

3 miles, terminating at its head in sand and gravel flats, and at high water connecting by a narrow passage with a lagoon about 1 mile in length by one-half mile in width, bare at low water.

One and one-quarter miles from Point Caution, nearly in the middle, but a little nearer the southern shore, is Healy Rock, low and bare; surrounded by rocky ledges of small extent, marked by kelp. On the northern shore, 1 mile SE. from Woody Point, is the Indian village of Neltushkin, and from the point immediately to the westward of the village a rocky ledge extends one-half mile in a SW. by W. direction, with a sunken rock one-quarter of a mile to the eastward of its seaward end, both well marked by kelp. In other particulars the description of this bay as given in the Pacific Coast Pilot, Alaska, Part I, is very good.

From the rocky islet off Woody Point, distant seven-eighths of a mile NW. by N., is Russian Reef. The position of this reef on the published charts is erroneous, as it has been placed much too far from shore, while in reality it is nearly on range between Point Caution and Distant Point. This reef extends three-quarters of a mile in a general WNW. direction, showing partially at low water, and is well marked by kelp. These rocks rise very abruptly from very deep water.

From Woody Point 2½ miles NE. ¾ E. is Rocky Point, the shore between being considerably indented by small open bights, with ledges extending well offshore at low water. There are also two small islands in this stretch, one close inshore, 1 mile S. ½ E. from Rocky Point, and the other one-half mile S. ½ E. from Rocky Point. From the latter island a rock, showing at half tide, lies NW., distant one-third mile. A larger island, distant 1 mile W. by N. from Rocky Point, has also a ledge, distant one-quarter mile NW. by W., showing at about half tide. This island and the white cliffs 2¾ miles south of Distant Point mark the entrance to a bay known by the Indians as Cha-ik, of which Village and Rocky Points are the north and south points respectively. In a shallow bight, just inside Village Point, is an Indian village, off which, distant one-half mile SE. by E., is an extensive ledge surrounding a small, low, bare, rocky island, and with a narrow channel between it and the shore.

This bay is about 3½ miles in length, and opens into an extensive flat at its head. On the north shore, 2 miles from Village Point, is a bight 1 mile in length in which is the anchorage. A low, wooded island, with a rock visible at half tide and distant 300 yards in a SW. direction from it, marks the southern point of the bight. In the middle of the bay, 1¼ miles E. by N. from the rock off the Indian village, is a low, wooded island with extensive ledges on the seaward side, and some detached rocks showing at low water on the inshore end. Between this island, and a little nearer the southern shore, are two rocks connected at low water. Beyond the island and these rocks, toward the head of the bay, the bottom is very irregular, and visible in many

places at a depth of 4 to 5 fathoms, and there is also an abundance of kelp. There are several small islands and rocks near the head of the bay, and vessels are recommended to avoid passing beyond the island off the southern point of the anchorage, the island in the center, and the two rocks near the southern shore.

In the inlet on the northern shore excellent holding ground in 12 fathoms, sticky bottom, may be had, and, although open to the southwest, it affords good protection from all other directions, and it is doubtful if it would blow home in southeasterly weather, the only wind which could draw in.

Distant Point is 3½ miles NNW. ½ W. from Village Point and 4½ miles SE. from Point Samuel. It marks the southern point of Hootz Bay, and directly behind it are two hills which lie between Cha-ik and Hootz Bay. The lower and more northern one lies directly behind the point, and from some points of view appears as a double peak of about 1,000 feet elevation. The larger mountain is about 2,200 feet in height, and is a single mountain rounded on top. Two and a half miles to the southward of Distant Point a spur of this mountain runs toward the water, and terminates abruptly in a whitish cliff 800 feet high, which has been previously referred to.

Kenasnow Island is low, and at its western end is about 300 feet high and heavily wooded. Much of the timber on the eastern end has been logged. Killisnoo, the location of the Alaska Oil and Guano Company, and the United States post-office, is situated on the northern and eastern end. Point Samuel is the western point of the island and the northern point of Hootz Bay.

From the entrance, Hootz Bay is about 11 miles long to the head of the southern arm, and about 10 miles to the head of the northern arm. In the entrance are numerous rocks and reefs, those visible lying close to the eastern shore and parallel to it for a distance of 2 miles, with a clear but narrow channel between them and the shore. Five-eighths of a mile N. ½ E. from Distant Point, and fully one-third of a mile offshore, is a sunken rock well marked by kelp, and care should be taken in rounding this point, either in entering or leaving, to give it a good berth.

Five miles inside on the northern shore is a low, wooded peninsula, off which, in mid-channel, are three rocks showing at low water. Two are comparatively small and close together, and about 300 yards nearer the entrance than the larger one, which covers at nearly high water. The bight to the northward of the peninsula is small and full of rocks and reefs. Several houses and shacks are located here. In proceeding up the bay the channel lies between the rocks and the southern shore. One and one-quarter miles farther in on the northern shore, and distant offshore some 300 yards, are two rocks, visible at low water. One-half mile beyond, the bay divides in two arms, a small, bare, rocky island lying about 200 yards off the dividing point. A ledge,

connected with the shore at low water, makes off for a short distance from a point just inside the north arm on its northern shore, but otherwise this arm is clear and affords an anchorage in 15 to 20 fathoms, soft bottom, at its head. The southern arm is also free from dangers, and gives an anchorage at its head in 15 to 20 fathoms, soft bottom.

Table Island, low and sandy, with extensive reefs bare at low water, lies three-eighths of a mile south of Kenasnow Island. A clear channel is between it and Kenasnow Island, leading to the anchorage off Killisnoo. The ledges off the southeastern point of Kenasnow Island are marked by a beacon, and Lone Rock, visible at half-tide, is marked by a second-class nun buoy, painted red.

Sand Island, 1 mile E. by S. from Table Island, is the northern point of the reefs and ledges extending along the eastern shore previously referred to. Between it and Table Island is a clear channel with 7 fathoms, leading to the anchorage off Killisnoo. The directions in the published sailing directions call for no changes, except as regards the buoy on Lone Rock.

From Point Gardner to Point Samuel the eastern shore of Chatham Strait is remarkable for many tide rips. On a calm night the noise of them is heard distinctly at a distance of a mile. These tide rips occur off nearly all the points and reefs, being particularly noticeable in the vicinity of Cha-ik Bay, Russian Reef, Point Caution, the reef in the entrance to Wilson Cove, and the point to the southward. They frequently extend a mile offshore, and at spring tides show much broken, white water. On the western shore of Chatham Strait between Point Thatcher and Point Lull there are no prominent indentations. Between Point Lull and South Point is Kelp Bay, which consists of a basin from which extend in different directions three arms. The northern one begins 3½ miles from Point Lull, and runs in a westerly direction for 3½ miles. At its head is an extensive flat that runs through, and at high water, spring tides, connects with a similar flat in Hanus Bay, in Peril Strait. At the highest tides there are probably from 3 to 4 feet of water on this flat, judging from the height of the seaweed and driftwood, but on the ordinary high waters there are but a few inches. At low water, from the head of this arm to Hanus Bay is a distance of 1¾ miles. Considerable logging has been done near the head, a large amount of cedar having been cut and rafted during this season. A short distance inside the entrance, close to the northern shore and connected with it at low water, is a small, low, wooded island. One and one-quarter miles farther in is another wooded island connected with the northern shore at low water, with several bare rocks close to its eastern end. Abreast this island on the southern shore a ledge makes off some 300 yards. Otherwise there is a clear channel to the head. An anchorage is not recommended in this arm, except for small craft that will find fair holding ground in from 8 to 10 fathoms. Scant swinging room will prevent its use by large vessels.

Off the point, separating this arm from the next one to the southward, ledges visible at low water extend 150 yards. This arm is clear from its entrance to its head, where it opens out into a moderate-sized flat. It is about 5 miles in length, and curves slightly toward the southward. With the exception of a shallow open bight, about 1½ miles inside on the southern shore, containing an extensive sand flat, this arm is devoid of any particular feature of interest. It affords a good anchorage near the head in from 12 to 18 fathoms, soft bottom.

The southern arm extends 3½ miles in a southerly direction, curving slightly to the southeastward. Two hundred yards off its eastern point is a sunken rock marked by kelp, clear of a mid-channel course, although the western shore should be slightly favored in entering. On the eastern shore, one-half mile from the entrance, are several small, wooded islets, connected with the shore at low water. A small open bight is one-half mile beyond them on the eastern shore. Abreast the islands and on the northern shore are several landslides on the face of a steep hill which shows plainly from Chatham Strait. Two miles from the head a point extending from the northern shore constricts the channel to a width of less than a quarter of a mile, beyond which it expands to a width of two-thirds of a mile, terminating at its head in extensive flats. The anchorage is at the head in 10 to 15 fathoms, soft bottom.

Five hundred yards SE. ½ E. from Portage Point is a sunken rock. One mile S. by W. from Portage Point is Plover Rock, small, but prominent, bare, with ledges of small extent. Near it are two rocks covered at one-third tide. The first is distant 200 yards ENE. ½ E., and the second is distant 750 yards S. by E. ½ E. from Plover Rock.

From the southern point of the south arm to South Point the shore forms a bight 1½ miles deep and 3½ miles wide from point to point. Across the entrance of this bight, and affording protection as an anchorage, extend several islands, the largest one lying close to shore near South Point, and a group of three lying off its western end, with a narrow channel between. These islands are all low and wooded, the large one containing two small lakes. Opposite the entrance to this narrow channel, on the north shore 2 miles from Point Lull, is a prominent whitish cliff, 800 feet high. Several sunken rocks were found in this channel. Three-quarters of a mile from North Point, NW. by W. ¼ W., is a sunken rock with a 4-fathom shoal between it and the point.

The shores of Kelp Bay are very abrupt and steep, and the northern shore is practically straight. From Point Caution, in Chatham Strait, a line down through the portage in the northern arm passes nearly through Broad Island, in Peril Strait, and the head of Hooniah Sound, a clear line 55 miles in length. Immediately to the westward of Point Lull is a narrow bight extending in a northwesterly direction for three-quarters of a mile. This is full of kelp, open to the southward, and affords temporary shelter for small craft only.

Between Pond Island and the south shore is a narrow passage full

of rocks and kelp. This is navigable by small boats, but should not be attempted by large vessels.

One and one-half miles to the southward of South Point a narrow inlet extends for 1½ miles to the westward. A small, rocky, wooded islet lies close to its northern point, connecting at low tide. Two hundred yards southeast is a bare rock with a ledge extending 150 yards to the southward. The entrance to the bight is from the southward, and it affords good shelter for small vessels, but is too narrow to give swinging room for vessels of any size.

For a distance of a mile below this bight the shore is straight, but from there to Ta-Katz Bay, a distance of 4 miles, the shore is much broken by bights, with several wooded islands and bare rocks lying close to shore. The cliffs are very precipitous, and several rather large waterfalls were noticed, one of which is very prominent, and has been referred to as one of the landmarks in this vicinity.

Ta-Katz Bay extends in a westerly direction, curving slightly to the southward for 2 miles, and then turns abruptly to the northward for another mile, terminating in a flat formed by a mountain stream emptying into it as a waterfall. This stream is evidently fed by a glacier, as the low water on ebb tide is milky at the entrance of the bay.

Point Turbot is the northern point, off which, at a distance of 75 yards, is a large white rock. SE. ½ S. from this rock, distant 250 yards, is a rock, bare at half tide. Off the southern point of the bay are four bare rocks, whitish in appearance and about 25 feet above water. On a line from Point Turbot to the southern point are two of them close together and distant from the southern point 300 yards, with reefs between them and the point, showing at low water. The other two rocks are 600 yards to the westward.

The southern shore of the bay is formed by a peninsula, which also forms the northern shore of a bight to the southward, with a group of small islands in its entrance. This bight does not appear to afford either shelter or an anchorage, the water being deep and kelp fairly abundant. Off the southern point of the bight, and to the southward of the group of islands, is a rock, bare at low water, 400 yards from shore.

Ta-Katz Bay affords a good anchorage in 20 fathoms, soft bottom, in the basin that opens out just before the turn to the northward. Chatham Strait is shut out entirely from the anchorage by the southerly curve of the bay, and the high surrounding hills give complete protection from all winds.

Warm Spring Bay, 4 miles below Point Turbot, is the northern point of a small bay 2 miles in length, extending to the westward. At its entrance the bay is nearly a mile wide, but the channel is narrowed to a half mile by a peninsula projecting from the northern shore. Nearly halfway between the two entrance points, and one-quarter of a mile off the eastern point of the peninsula, is a small bare rock about 15 feet

above water. On the southern shore are two small bights, and at the head of the bay a small lagoon to the left of the waterfall previously spoken of. This waterfall is the outlet of a lake several miles long, about 200 feet above sea level. Near this waterfall, and at some considerable height above it, are several warm mineral springs, frequented by Indians on account of their medicinal properties. This bay affords an anchorage in 25 fathoms, rocky bottom, beyond the peninsula and abreast the second bight on the southern shore. While affording fair shelter from northerly winds, in southerly weather the wind and sea draw in around the southern point. This, coupled with rather poor holding ground and deep water, renders it undesirable as an anchorage in bad weather.

Between this bay and a point opposite Point Gardner are two open bights, both unsuited for anchorages. The southern one is called Cascade Bay, from the very prominent waterfall at its head.

The hand lead is of little use to navigators in these waters in thick weather, 20 and 30 fathoms being frequently found within a few yards of the shore line, while a quarter of a mile from the beach 100 to 200 fathoms are not at all unusual.

One almost universal feature which exists in these waters is the occurrence of sand and gravel flats, with one or more small streams at the head of all bights and inlets. The slope, from 8 to 10 fathoms to a few feet, is very abrupt, and in approaching the head of an inlet at high water care should be exercised in anchoring to give the flats a sufficient berth to avoid grounding at low water. Nearly all afford good holding ground, in soft or sticky bottom, within a short distance of the head.

### HOOTZNAHOO INLET.

Hootznahoo Inlet, comprising an area of about 15 square miles, is a group of lagoons and bays on the eastern shore of Chatham Strait, 2¾ miles above Killisnoo. It consists of five principal divisions, full of rocks, reefs, and shoals, connected by narrow channels through which the tide flows with great force, attaining at times a velocity of from 10 to 12 knots per hour.

The entrance to these lagoons is between Danger Point and Hootznahoo Head, and from the entrance extends in a general easterly direction for 3½ miles, where it opens out into a small bay, called "Favorite Bay" by the Alaska Oil and Guano Company, who use it considerably as a fishing ground for herring.

One and one-half miles from the entrance on the north shore, and extending to the northward, are two arms, the western one being almost straight, with the exception of a small bight on its western shore, and connecting with Mitchell Bay. The eastern arm joins the western at Point Pillsbury, above the end of Long Island, which lies between the arms. On the eastern shore of this arm is a small passage opening into

a lagoon that at high water connects at its southeast end by a passage with Favorite Bay. At its northern end it connects by a narrow passage with a lagoon opening into Mitchell Bay.

Mitchell Bay, the largest of the divisions of this inlet, is about $4\frac{1}{2}$ miles in length by an average width of $1\frac{1}{2}$ miles. At its southwest end it is connected with a lagoon so full of rocks, reefs, and shallow water that soundings were considered unnecessary. At its southeast end it is connected by Davis Creek to Kanalkoo Bay and Lighter Creek. At its northern end it is connected by a lagoon, impassable except at high water by small boats, which is said to connect with a series of lakes in the interior of Admiralty Island.

It is impossible to give more than a general description of this mixed-up mass of islands, rocks, and water, as a much better idea can be obtained from the charts.

The general character of the country is low and rather heavily wooded, except where otherwise noted, and the absence of prominent features renders it impossible to give ranges that would be of much service to the navigator. The names have been taken from the description of this place written by Captain Meade, U. S. N., who navigated these channels in 1869 in the U. S. S. *Saginaw*, and his description is apparently very full and complete.

At the present time there seems to be little to induce a vessel to enter these waters. The indications of coal, or, more properly, lignite, are numerous, but the mines have not been worked for a number of years, and any subsequent development of them would not depend upon these waters as a means of disposing of their output, since a short railway system of a few miles would lead directly to Chatham Strait abreast of Killisnoo.

### SAILING DIRECTIONS FOR HOOTZNAHOO INLET.

On the north side of Danger Point is the narrow entrance to an extensive system of inlets and lagoons, called by the Indians "Hootznahoo."

The entrance is about one-half of a mile wide, gradually narrowing, but free from obstructions, until Village Rock is reached. This is a large low-water ledge making out from an Indian village on the south shore toward Turn Point on the north shore.

This ledge obstructs more than one-half the channel, and the strength of the tide causes a very strong current, running at times probably as high as 8 knots, with large swirls where the current impinges upon the larger and slower moving body of water.

Beyond Village Rock, to the eastward, the channel is clear on the south side well in toward the shore line, but on the north side it is obstructed by a ledge marked by kelp at slack water making out from Turn Point, terminating in a large round-top rock, which covers at high water and upon which a spindle has been placed by the Alaska Oil and Guano Company.

One-quarter of a mile beyond this rock begins a series of rocks, uncovered at low water, extending to the unbroken shore line on the south side of the channel leading into Favorite Bay, in a line with this shore, the spindle, and Turn Point. At the spindle rock the channel branches in three directions. One branch continues to the eastward past Sullivans Point, which has been prospected for coal, and leads into Favorite Bay, a large lagoon filled with herring during the season. The other two go to the northward and eastward on either side of a large wooded island.

The eastern of these passages is obstructed at the south end except for small boats, and at the north end of the island divides, one branch reuniting at Point Pillsbury with the main passage leading into Mitchell Bay, the other going through a very narrow channel into a large lagoon full of rocks and reefs, and unnavigable except for small craft. This lagoon is connected at its southeast corner by a high-water passage with Favorite Bay, and on its northeast side past a series of islands and broken reefs with Mitchell Bay.

From the spindle on Rose Rock the westernmost branch turns sharply to the westward along the reef making out from Turn Point, thence to the northward and eastward for 5 miles, when it opens into Mitchell Bay. One and one-quarter miles above Turn Point this channel runs between a ledge of rock making off to the southward from Point Pillsbury and a round, bluff, high-water island; thence for one-half mile between reefs to Point Bridge, where it runs between a reef on the west side and a bold bank on the east side into a narrow channel with steep bold shores on either hand.

Three-quarters of a mile above Point Bridge the channel broadens to a width of one-quarter mile until near the entrance to Mitchell Bay, when it is again confined between a ledge making off to the southward from North Point and a system of high-water islands to the eastward. Beyond North Point is Mitchell Bay, which extends to the northward and eastward a distance of 4½ miles, with a width of 1½ miles at its south side to narrow channels at the north, and leading over rapids into a system of lagoons fed by a large stream, said to have its source in lakes near the middle of the island. At the southeast angle of this bay is a narrow passage called Davis Creek, which, after running in a southeast direction through a very foul channel, turns back upon itself and widens into a clear open basin, called Kanalkoo Bay, at the head of which are two large streams. One-half mile from the north end of Davis Creek, Lighter Creek makes off, having from 2½ fathoms to 5 fathoms of water at high tide.

The south shore of Mitchell Bay is very foul, and while there is an ebb and flow of tide from Hootznahoo Head to Mitchell Bay, to the eastward of the main passage there is no channel for any sort of craft larger than rowboats and canoes. Near the west side of Mitchell Bay and 1¼ miles from the entrance to Diamond Island, is a long narrow island, sparsely wooded, with a large timber fall. To the eastward of

this island, and in a line parallel with the south shore of the bay, are two islands, one, a small, round, high-water island, without timber, the other larger and covered with a dense growth of timber.

To the northward of these islands there is a larger island with a confined channel to the west of it. At the entrance to Davis Creek is a high-water island, called by Captain Meade "Passage Islet." A large stream empties into Davis Creek at its north end, near which, in Mitchell Bay, a good anchorage may be had in from 10 to 20 fathoms of water.

The tides in this system of lagoons continue to run from one hour to one and one-half hours after the change at Hootznahoo Head, or even longer. Slack water will be found at Village Rock, in the narrows; at Points Pillsbury and Bridge, at North Point; and at the south entrance to the middle lagoon, from one hour to one and one-half hours after the change of tide at Hootznahoo Head. Slack water at the north end of Davis Creek occurs half an hour after high or low water in Mitchell Bay.

Vessels rounding Rose Rock at slack water would carry slack water all the way to Mitchell Bay. At Village Rock the currents run from 5 to 8 knots; at Point Bridge as high as 10 knots, and at Passage Islet as high as 7 knots.

Coal has been found in small quantities about the entrance to Davis and Lighter creeks, at the southeast corner of Kanalkoo Bay, and in the middle lagoon.

Several abandoned tunnels and shafts appear about Davis and Lighter creeks.

### PERIL STRAIT.

Peril Strait is one of the most important waterways in southeastern Alaska, rivaling Wrangell Narrows in the amount of its commerce, and is the only connection between the inland channels and Sitka. It is used by small sloops and schooners, by small steamers employed in the interest of various canneries, sawmills, and mines, by the regular mail steamers throughout the year, and during this last season by two steamers running in opposition to the Pacific Coast Steamship Company from Puget Sound to these waters.

An excellent reconnoissance of the narrows from Suloia Bay to Pogibshi Point, including also the steamer track from that point to Broad Island, was made by the officers of the U. S. S. *Adams*, under Commander J. B. Coglan, United States Navy, in 1884, and but few changes were found by the present survey.

The north shore of Peril Strait from Point Craven to the head of the northern arm of Hooniah Sound is steep and bold, and after passing Lindenberg Head is practically a straight line, with no dangers except an occasional flat of small extent making off the mouth of a stream. The shore can be approached with safety to within a quarter of a mile. The mountains are covered with a moderate growth of timber and underbrush, their tops being generally bare and rocky except where noted on the sheet.

McClellan Rock, marked by a spindle immediately off Lindenberg Head, and a sunken rock off a small open bight, 2 miles to the eastward of Lindenberg Head, are the only dangers from this point to Point Craven. The principal landmarks in Peril Strait are Fairway Island, in the eastern entrance; Lindenberg Head; the point at which Peril Strait changes direction; a series of bare, rocky hills and cliffs 2½ miles above Lindenberg Head, and Broad Island, lying three-quarters of a mile off the northern shore at the western end of the strait. Several landslides will be referred to later. The southern shore of Peril Strait is much indented by small bights, coves, and inlets, and although the mountains back of the shore line are in many instances higher than those of the northern side, the slopes are generally less abrupt.

Point Craven is the western point of a narrow inlet known as Sitkoh Bay, about 6½ miles in length, that extends in a general northerly direction. The point consists of an outlying rock, about 10 feet in height, with a larger and higher rock nearly halfway between it and the shore, connected by ledges showing at low water. A small, steep bluff is on the rounded point of the shore behind the rocks. Deep water can be carried close up to these rocks.

The eastern point of Sitkoh Bay is Point Hayes, distant from Point Craven 1¼ miles N. by E. ¾ E., and bearing SSE. ½ E., distant 1½ miles from Peninsular Point, in Chatham Strait. This portion of the shore is extremely foul and dangerous, the bottom is irregular, and kelp is particularly thick. From Point Hayes, extending toward Point Craven across the mouth of Sitkoh Bay for a distance of half a mile, are numerous reefs and ledges, some of which are visible at low water only. Two small islands and a rock lie a short distance off the point. A first-class can buoy, painted black, is moored 1⅞ miles NE. by E. ½ E. from Point Craven and 2⅞ miles N. by W. ¼ W. from Point Thatcher. Between this and Point Hayes is very foul and dangerous ground, and no vessel should attempt to pass to the northward of the buoy under any circumstances. On line between the buoy and Peninsular Point is an extensive reef, usually well marked by kelp, which shows partially at low water and runs in a generally northern direction. A line from the outer rock of Point Craven drawn through the small bare rock off Point Hayes passes nearly through the center of this ledge. To avoid this ledge, in entering Chatham Strait from Peril Strait, with the buoy close aboard, a NE. ½ E. course should be held until the prominent white rock to the northward of Peninsular Point is well open before hauling to the northward. Sitkoh Bay for the first 2 miles is about 1 mile in width, though the channel at the entrance is constricted to half that distance by the ledges and reefs making off to the westward from Point Hayes. Two miles above Point Hayes, from the eastern shore, projects a low, heavily wooded point, which forms a bight, affording an anchorage in 20 fathoms, hard bottom, and excellent protection from the northerly gales, which are the severe winter winds. Behind the point is a small

bar. This bar is much larger than would ordinarily be expected, and extends fully halfway across the inlet. Beyond it there are no obstructions until the flats at the head are reached, 1 mile beyond the ravine. A good-sized stream, noted for large numbers of trout, empties at the head. The anchorage is five-eighths of a mile beyond the bar, in the middle of the inlet, in 18 to 22 fathoms, soft green mud. Excellent water can be obtained from any of the numerous small streams that come in on each side of the anchorage, preferably at high water, when a better approach to them can be had. Peril Strait is entirely hidden from the anchorage.

Four and one-half miles farther, on the south shore, is the entrance to an inlet, Rodman Bay, which extends to the southward for 6 miles. Its western point is high and well wooded, with reefs extending offshore for about 100 yards. The eastern point is low, and between it and a small cove on the eastern shore are several rocks, bare at low water, but not generally visible. This inlet is 6½ miles from Broad Island and 8 miles from Lindenberg Head. At the entrance it is about 2 miles wide, but contracts in 1½ miles to five-eighths of a mile, a small wooded island lying off the eastern side, where it narrows. The soundings in the entrance are very irregular, and although no dangers were found care should be taken in entering. On the eastern shore, close to the entrance, is a small cove with an island in the middle of the entrance connected with the southern point by a sand spit covered at high water. The channel for entering is on the north side of the island. The cove has rocks and shoals, and affords an anchorage to small craft only. A stream empties at its head with very extreme flats.

On the western shore of the inlet, 2 miles from the entrance, a shoal extends offshore for about 125 yards, but otherwise the channel is clear to the head, where extensive sand and gravel flats make off from the southwest corner. On the eastern side, near the head, are two islands, connected at low water, and just beyond them, with a point on the eastern shore showing between, a good anchorage may be had in 10 to 12 fathoms, soft bottom. A large stream coming from the eastward through a narrow valley empties in this corner of the head with extensive sand and gravel flats.

Two miles west of Rodman Bay is Pestchani Point, low and wooded, on the eastern side of which a mountain stream empties, forming a very large sand and gravel bar. This flat extends into the channel for over a quarter of a mile, from one-half of a mile to the westward of the point to below the mouth of the stream. A close approach to the point should be avoided. Three-quarters of a mile west of Pestchani Point is Nismeni Point, low, covered with a thin growth of trees, bare and rocky at its seaboard end. Off this point are two ledges, bare at low water only, with a sunken rock halfway between them and the point. The first is distant 600 yards NE. ½ E. and the second is distant 800 yards NE. ½ E. from the point. To the eastward of the point is Nismeni

Cove, about three-quarters of a mile in depth by less than one-half of a mile at its entrance. This gives shelter from southerly winds, the holding ground in the middle of the cove being fair in 18 to 22 fathoms. The course for entering lies toward the eastern point to avoid the ledges off Nismeni Point. This bight affords no shelter from northerly winds.

Beyond Nismeni Point and Broad Island, Peril Strait opens out into a considerably wider body of water, extending 7 miles to the southward to Point Pogibshi, the northern entrance to the narrows, and on its western side opening into three bays, the two northern ones being the most extensive and constituting Hooniah Sound. To the southward about $3\frac{1}{2}$ miles, on the western shore, the third bay extends in a curve to the southward for 4 miles.

Poison Cove, near Point Pogibshi, is the only other indentation on this shore.

From Nismeni Point to Point Pogibshi the shore bends in a gentle curve to the southward, the low water line extending some considerable distance offshore. Several anchorages may be had along this shore, the best being near Point Pogibshi off the entrance of a small lagoon in a small grassy flat, in 22 fathoms, sandy bottom. A close approach to the shore should be avoided in anchoring, as an extensive sand and gravel bar makes out well into the bight.

One mile SW. by W. $\frac{1}{2}$ W. from Nismeni Point is Otstoia Island, low and thickly wooded, and connected at low water with two bare rocks lying off its southwestern end. A sand and gravel bar, formed by mountain streams, makes off from the shore toward Otstoia Island, constricting the channel to a width of one-eighth of a mile. The outer point of the flat is marked by a second-class red can buoy, anchored in 8 fathoms. A clear channel, carrying 4 to 10 fathoms, generally used by the steamers, lies between the buoy and Otstoia Island, and a straight course from the buoy to Poverotni Island clears all dangers.

Three-quarters of a mile W. $\frac{3}{4}$ S. from Nismeni Point is the seaward end of Cozian Reef, a sunken ledge extending off Otstoia Island for nearly one-half mile. Its outer end is marked by a second-class can buoy, painted black. One-half mile SW. by W. $\frac{3}{4}$ W. from Nismeni Point, and lying 150 yards offshore, is a sunken rock poorly marked by kelp.

Five-eighths of a mile W. by S. from the southern end of Otstoia Island are Krugloi and Elevoi islands, connected at low water. These islands are small, low, and wooded. Between them and Otstoia Island is a clear channel with from 12 to 25 fathoms, which is apparently a better one than that between Otstoia Island and the shore, as it avoids Cozian Reef and the sunken rock between it and the shore.

One and one-half miles from Krugloi Island and nearly on range between it and the northern point of Ushk Bay is a reef nearly 150 yards long, baring only at spring low water. A little inshore, but

nearly on range between Point Emmons and the north point of Poison Cove, is a reef of about the same extent as the last, distant $2\frac{5}{8}$ miles S. $\frac{1}{4}$ E. from Point Emmons and $2\frac{1}{2}$ miles SW. $\frac{1}{2}$ W. from Krugloi Island. It is seven-eighths of a mile NE. $\frac{3}{4}$ N. from the southern point of the Ushk Bay, and bares at low water only. One and one-half miles SW. $\frac{3}{4}$ S. of Krugloi Island and $2\frac{1}{2}$ miles N. from Poverotni Island is the center of a group of reefs, with shallow water between, covering an area of one-half mile square. The largest of these is about 300 yards long by from 50 to 100 yards in width, composed of sand, gravel, and bowlders. This covers only at the highest spring tides. Four hundred yards to the southward of this are two low rocks, covered at ordinary high water. To the westward of the sandy island about one-quarter of a mile are three ledges, covering at about half tide. The white sandy bottom between these ledges and extending off them for a distance varying from 50 to 150 yards is visible for a considerable distance on a bright day. Between these reefs and Poverotni Island there are no dangers, the water varying from 30 to 50 fathoms in depth.

Poison Cove, abreast Poverotni Island, is a small open bight, with low gravelly beaches, and flats at the head that uncover for a quarter of a mile at low water. It is free from dangers and affords an anchorage for small craft in 18 fathoms, soft bottom.

One and one-half mile to the northward is the entrance to Ushk Bay, which extends to the westward and southward for 4 miles, with an average width of three-quarters of a mile, narrowing to one-third at the point where it changes direction. It affords an anchorage at the head in from 18 to 20 fathoms, soft bottom. A peculiar formation of the hills is noticeable near the entrance on the southern shore, and a solitary round-topped hill, 1,800 feet high, with several landslides, marks its northern point and the southern entrance to Hooniah Sound.

Five miles N. by W. $\frac{1}{4}$ W. from Poverotni Island and 4 miles WSW. from Broad Island is Emmons Island, Point Emmons being its eastern extremity. This island was named in honor of Lieut. George Emmons, U. S. N., who has spent many years in these waters and furnished much valuable information in regard to them and the habits and customs of the Indians in this section of Alaska. The island is well wooded and has a small lake on its northern side. A ridge in the center, 600 feet high at its eastern end, has the appearance of a cone to vessels coming from Chatham Strait.

Off the western end of Emmons Island, distant one-half mile, is a group of small wooded islands, connected at low water, from which a reef, bare at half tide, extends to the northward for nearly one-half mile. The passage between the south shore of Hooniah Sound and Emmons Island should not be attempted, as the water is shallow, and long sand spits, visible at low water, make well into the channel from the western end of Emmons Island and the small group of islands to the westward.

Two and one-half miles WNW. from Emmons Island, a large island, 5 miles in length, 1½ miles wide at its eastern end and 1 mile wide at its western end, divides Hooniah Sound into two arms. A sand spit, one-quarter mile in length, covered at high water with a small, wooded, high-water island near its center, connects the large island with the shore at its western end. On its southwestern end is a prominent landslide. Off its eastern end a ledge makes off for 250 yards, and off its southeastern point is a ledge distant 250 yards ESE., bare at high tide. One mile to the westward from its eastern end, and one-third mile off the northern shore, is a small bare rock, some 8 feet out of water at high tide. The northern shore is low, with sand and gravel beaches which extend offshore 150 to 200 yards for a mile above the bare rock. The southern shore of the island is bold and steep.

Five and one-half miles beyond Emmons Island, the south arm of Hooniah Sound is divided into a bay, 3 miles long, extending to the southward, and a smaller arm, 2 miles long, that connects with the northern arm at high water. Three and one-half miles above Emmons Island is a small bight, with flats at its head, bare at low water. Off its eastern point is a small, round, wooded island, connected with the shore at low water, from which a reef extends to the eastward for 200 yards. The southern shore should not be approached too closely, as the low water line extends well out. The bay extending to the southward is clear except for the western shore, which is shoal, with several sand and gravel bars. The arm at the head connecting with the northern arm, in addition to extensive mud and sand flats, has a low grassy flat, covered here and there by small bushes, extending through on the left of a small wooded knoll to similar flat 2½ miles above the junction of the north and south arms. In this small connecting arm, one-half mile NNW. ½ W. from the wooded island on the sand spit, and in mid-channel, is a rock, bare at low water. This rock is about 2¼ miles above the southern point of the arm.

The northern arm of Hooniah Sound is comparatively clear, until one-eighth of a mile to the southward of the small island on the northern shore, where, in mid-channel, is a rock, bare at low water. This rock is not quite abreast of a prominent waterfall on the north shore. At the head of the northern arm are two streams, both small, entering from low valleys, one extending in the same general direction as Hooniah Sound, and the other having a more southerly trend. A wooded island, with a reef extending one-quarter mile to the eastward, lies off the point of the ridge dividing the two valleys and is connected at low water with the shore by the flats at the head.

## SAILING DIRECTIONS FOR CHATHAM STRAIT, POINT GARDNER TO POINT SAMUEL.

If coming up the strait from the sea, keep a mid-channel course, about NW. by N. It is safe, however, to approach a line drawn half a mile from one prominent point to the same distance from the next, as all dan-

gers will lie inshore of this line. In coming from Frederick Sound give Point Gardner a berth of 1 mile, because to the south of it has not been surveyed, and the strong currents and heavy tide rips in its vicinity indicate irregular bottom. With Point Gardner abeam NE. by E., the course is NW. ¾ N. to clear Point Caution 1 mile, where there are also heavy tide rips. If bound up the strait, continue this course, which will probably carry to Point Marsden, by making due allowance for tidal currents. If bound for Killisnoo, having run 15 miles and Point Caution bearing E., change course to N. by W. ½ W. If bound up Peril Strait, run 27 miles, when Fairway Island should bear SW. by W., north of Midway reef; then change to WSW., keeping in mid-channel north of Fairway Island.

Wilson Cove is not recommended for an anchorage, but should it be necessary, stand in parallel to the south shore, about N. by E. ½ E., midway between the reef in the mouth of the cove and the south shore, keeping clear of the kelp, and anchor in 8 to 10 fathoms.

Whitewater Bay.—The directions in the Pacific Coast Pilot, part 1, p. 157, are good.

Cha-ik Bay.—Stand on until the bay is wide open between the two low, flat islands in its mouth, not wooded, one off Rocky Point and the other inside of Village Point, when stand in about NE. by E. heading for a low wooded island in the middle of the bay. When halfway between the island off Village Point and the low, wooded island an arm will open to the northward. Steer for the mouth of it, about NNE., and anchor in the middle, in 12 fathoms, sticky mud bottom. The south arm should be avoided, except by small vessels, on account of shoals, rocks, and kelp.

Hootz Bay.—From off Distant Point follow the shore on the south side, keeping about half a mile away to clear the sunken rock until the mouth of the inner bay opens, when steer for it about SE. by E. ½ E., favoring the southern shore to clear an island, and some sunken rocks close to it, in the middle of the narrowest part. After passing the island keep in the middle until reaching the divide, when take the middle of either arm desired. It is spacious and easy of access with anchorage anywhere in the north arm in 20 fathoms or less, and at the head of the south arm in 18 fathoms, with muddy bottom and good protection. From Killisnoo there is a good channel with plenty of water inside of the line of islands and reefs. Keep in the middle, steering about SE. by E. ¾ E., avoiding kelp.

Cascade Bay.—Opposite Point Gardner, requires no special directions. Stand into the middle about WSW. until you can get bottom in about 25 fathoms, then anchor. It is not recommended except for small vessels unable to work up against a northerly wind. The cascade can be seen to Point Gardner.

Warm Spring Bay.—Open up the mouth of the bay, when stand in about SW. by W., midway between a white high-water rock in its center

and the south shore, which is bold. A small vessel can anchor in either of the two small bays on the south side and have good protection from southerly winds. The western one is preferable because of shoaler water—12 to 15 fathoms. A large vessel must go near the cascade at the head to get 25 fathoms and yet have swinging room. This latter is not recommended, as the bottom is rocky and the current usually sets out, caused by the flow of water down the cascade from the large mountain lake at the head, making a vessel lie broadside to the south wind, which sucks in and caroms on the steep mountain side north of the bay, sheering her about very uncomfortably.

Ta-Katz Bay.—This is the best protected anchorage on this part of the coast, being entirely surrounded by high, rocky walls, but might be difficult to enter with heavy southerly sea. The anchorage is in the northern arm, and the entrance is not visible until close in to the southward of Point Turbot. When three-eighths of a mile ESE. from Point Turbot, steer SW. ½ W. for the middle of the entrance, between the high-bluff north shore and the high-water rocks off the high-wooded promontory which divides the bay. This clears the low-water rock 250 yards SE. from Point Turbot and the one inside of the promontory point near the north shore. When past the promontory point, favor the south shore to clear a sunken rock and kelp patch near the middle, though it can be left on either side. Anchor near the middle of the bay in its widest part in 20 fathoms, soft, sandy bottom. Or, if desired, round the second point and anchor in 10 fathoms, with plenty of swinging room. Do not pass a white lump of an island around the second bend, for there the sand flat begins. The south arm is not recommended. The water is deep, and the bottom is rocky and irregular, with occasional kelp patches.

Kelp Bay.—Open up the mouth and stand into the middle, about WNW. ½ W., giving Point Lull and North Point a berth of 1 mile to clear a reef making off from Point Lull to the SE. An anchorage can be had at the head of either of these arms, with soft bottom, in 18 to 24 fathoms, having a care not to approach too near the head at high tide, because of the flats. The only directions are to keep in the middle. The shores are bold, but ledges make out from some of the points which do not show at high water. The best anchorage is in the southeast corner of the basin, close under a high bald knob. Stand in until clear of the sunken rock northwest of Crow Islands, when haul around the islands, favoring them, to clear a low-water rock not marked with kelp, about the middle. Course about SE. by S., keeping the bald knob open on the starboard bow, and anchor close under it in 20 to 24 fathoms. This affords excellent protection except from northwest.

There is a fair channel between Crow and Pond Islands used by the Patterson. There are two sunken rocks in it surrounded by kelp. No directions can be given for it, except keep near mid-channel and clear of kelp.

**Hootznahoo Inlet.**—Round Danger Point buoy and steer a mid-channel course until the Indian village on the south side shows clear of a bluff, when favor the north shore until past Turn Point, then steer to clear Rose Rock. Round Rose Rock, keeping it close aboard, and if bound for Favorite Bay stand well over for the coal mine on Sullivans Point, until midway between the unbroken shores of the channel leading into Favorite Bay. Keep in mid-channel until the fishing camp on the south shore is reached, when favor either shore to clear a rock in mid-channel, uncovered at low water and marked by a box on a tree on the south shore.

A good anchorage may be found in Favorite Bay anywhere to the westward of a high bluff on the south shore, marking the limits of extensive flats.

If bound for Mitchell Bay, round Rose Rock, keeping it close aboard, and stand close along the reef making out from Turn Point. When well clear of the south end of the island dividing the channels leading to the northward, steer for the entrance leading to the narrows at Point Pillsbury. Upon approaching the narrows, keep the island on the south side close aboard until in mid-channel beyond; there the course is mid-channel until near Point Bridge, when the eastern shore must be favored. Beyond Point Bridge the course is again mid-channel until within 1½ miles of the entrance to Mitchell Bay, when the timber fall on Diamond Island, kept in the middle of the opening between North Point and a small, low, round, high-water island on the south side, will carry clear of the reef on the west side and a rock on the east side. After entering Mitchell Bay, follow the west shore and pass midway between Diamond Island and the shore. Beyond Diamond Island clear open water will be found and a good anchorage in the southeast corner in 10 to 20 fathoms of water.

The passage from Mitchell to Kanalkoo Bay is so full of reefs and so devoid of permanent landmarks that could be used as ranges that no sailing directions can be given.

The navigation of Hootznahoo Inlet and its lagoons is such that it should not be attempted except by small vessels of short length and ready turning qualities—and then only at low water slack, at which time all dangers are exposed—unless a pilot with local knowledge can be obtained.

## SAILING DIRECTIONS THROUGH PERIL STRAIT FROM POVEROTNI ISLAND TO CHATHAM STRAIT, COMING FROM THE SOUTHWARD.

The sailing directions from Sergius Narrows to Poverotni Island as given in the Pacific Coast Pilot, Alaska, Part I, are correct.

Poverotni Island may be passed to the northward at a distance of about 200 yards. There is a passage between Pogibshi Point and Poverotni Island, but is not recommended. When it bears abeam, steer for Otstoia Island, course NNE. The usual steamer track is to

the eastward of the island, but there is a good passage to the westward, between it and Krugloi and Elevoi Islands. If passing it to the eastward, favor the island side, leaving the red buoy on starboard hand. After passing the black buoy on Cozian Rock, steer NE. ¼ E. for the easterly one of the two big landslides on northern shore until the northeast end of Broad Island bears W. by S.; then steer E. ⅝ S. until False Lindenberg Head is abeam; then E. by N. until McClellan Rock is abeam, and thence into Chatham Strait, the course is NE. by E. This course will carry across Chatham Strait south of Kenasnow Island, making allowance for tides. If going to the westward of Otstoia Island, after passing the island, do not steer to the eastward of a line joining the western side of Otstoia Island and the eastern side of Broad Island until the buoy on Cozian Rock is passed. This clears Cozian Rock and Shoal.

ANCHORAGES BETWEEN POVEROTNI ISLAND AND CHATHAM STRAIT.

Poison Cove is free from dangers and affords an anchorage for small craft in 18 to 20 fathoms. No special directions are necessary for entering.

Pogibshi Point.—On the north side, in broad, shallow bight, about two-thirds the distance from the point to a small stream, there is a good anchorage in about 22 fathoms, soft sandy bottom.

Favorite anchorage.—As described in Coast Pilot.

Nismeni Cove.—Favor the eastern shore to avoid the ledges off Nismeni Point, and anchor in the middle of the cove in 18 to 22 fathoms.

Lindenberg Harbor.—As described in Coast Pilot.

Sitkoh Bay.—Pass Point Craven at a distance of 200 yards, and favor the western shore for a mile, then steer for the middle of the bight on the eastern side, anchoring in 18 to 25 fathoms, hard bottom. A better anchorage can be had at the head of the left arm, in about 20 fathoms, soft bottom. No special directions are necessary. Keep in the middle.

Rodman Bay.—On entering, keep a mid-channel course about SW. ½ S., and anchor to the southward of two small islands at the head of the bay in 10 to 15 fathoms, soft, sandy bottom. The extreme western point on the eastern shore of the bay will show between the islands when on the anchorage.

Sa-ook Bay.—Keep a mid-channel course about SW. by S. until abreast of the first of a small group of small islands near the eastern shore; then favor the eastern shore, keeping at a distance of 100 yards, until past a stream on the western shore from which a sand spit makes out. The anchorage is about half a mile farther on in the middle of the inlet in 18 to 22 fathoms; soft, green mud.

Hanus Bay.—Is not recommended for large vessels. There are two coves at its western end which may be used by small craft.

Point Thatcher.—Inside of Point Thatcher there is an anchorage formerly used by the Russians, but it is not recommended, as it affords

very little protection. Keep in mid-channel between Point Thatcher and Midway Reef until well inside the point and anchor in 15 to 20 fathoms, rocky bottom, midway between the two extreme points of the first bend in the shore line.

Hooniah Sound.—Needs no special directions. The north arm is clear until near its head, where there is a rock, bare at low water, in the middle, to be avoided by favoring the south shore. The entrance to the south arm from Peril Strait should be navigated with care, following the deep water as shown by the chart. An anchorage can be had at the head of either of the three arms in 15 to 20 fathoms, soft bottom, having a care at high tide not to get on the flats.

Ushk Bay.—Needs no special directions. Keep in the middle and anchor near the head. Better directions can be written when the chart is issued so that courses can be taken and corrected soundings had.

## TIDES AND CURRENTS.

In the vicinity of Killisnoo the currents are very irregular, but the means show that the last half of the ebb and the first part of the flood sets in through Hootz Bay and sets out to the westward through the north channel. The second half of the flood and the first half of the ebb set into the eastward through the north channel and out into Hootz Bay.

The set is parallel to the axis of the channel, and the strength is not important except in the narrow part of the north entrance. The current at the wharf is even more erratic than that in the channel, but is not so strong; sometimes, however, an eddy will be found, but not strong enough to interfere materially with making a landing. At Killisnoo the following data was obtained by observation:

| | |
|---|---|
| Average time of high water after moon's meridian pass is.. | $0^h\ 24^m$ |
| Average time of low water after moon's meridian pass is... | $6^h\ 32^m$ |
| Mean rise and fall is.................................... | 11.5 feet. |

Hootznahoo Inlet.—The currents are strong and various all through this place, and the uninitiated should not attempt to navigate it except at slack water, and had better choose low slack, so that in case of grounding the benefit of a rising tide will be obtained. The flood current at the entrance sets in nearly parallel to the north shore and so continues until it reaches Village Rock, where it divides, one part going to the northward over what Meade calls "Hell's Acre," and the other continuing to the eastward south of Rose Rock, where it again divides. One part continues east into Favorite Bay, while the other turns short around the rock and divides again, one part going north, the other branch passing over "Hell's Acre."

The rapids begin at Village Rock and continue until well past Rose Rock.

The strongest current observed in the channel was 6.2 knots, but this is not the strongest. It probably reaches 8 knots at times.

It is slack at about one hour and thirty minutes after high and low water at Killisnoo.

The channel connecting Mitchell Bay with the lower part of the inlet commences at Point Pillsbury. From this point to Point Bridge the current is very swift, probably reaching 10 knots, with much boiling and swirling, the worst place being at Point Bridge. This can only be passed at slack water, which lasts only a few minutes and occurs about one hour and fifty minutes after high and low water at Killisnoo.

Through all of the narrow channels leading into the various bays the currents run with great velocity, and they should not be attempted in any kind of a boat except at slack water.

Pogibshi Point.—At Pogibshi Point the following data was obtained by observation:

| | |
|---|---|
| Average time of high water after moon's meridian pass .... | $0^h$ $29^m$ |
| Average time of low water after moon's meridian pass ..... | $6^h$ $42^m$ |
| Mean rise and fall .................................... | 12.4 feet. |

Sergius Narrows.—From the observations made it is concluded that the flood current coming in through Salisbury Sound flows up through the Narrows and into the broader part of Peril Strait, north of Pogibshi Point, when it meets the flood that has come up through Chatham Strait and into the eastern end of Peril Strait. Just where in this broad part they meet is uncertain, but from the observations made it is concluded that both currents spread out and lose themselves.

The time of slack water in Sergius and Adams Narrows varies from one hour and thirty minutes before high and low water, to two hours and thirty minutes, the average being about two hours. The slack high seems to come earlier than the slack low, and seldom comes less than two hours before high water, while the slack low seldom comes more than two hours before low water.

The duration of slack is only a few minutes, in fact, sometimes it ceases to run in one direction and immediately starts in the other, and is not half an hour as stated in the Sailing Directions. There is half an hour, however, when the current does not exceed two knots, and the surface is comparatively smooth, and vessels may go through with safety.

The strongest current observed was 8.2 knots. It is probable that it reaches 10 knots at spring tides, and boils and swirls in such a manner that navigation is unsafe from below Francis Rocks to Leisnoi Island.

## COOKS INLET AND TO THE WESTWARD.

The following information concerning Cooks Inlet and the region to the westward is compiled from the notes of Prof. W. H. Dall, U. S. Geological Survey, made by him in the summer of 1895, and published in the March bulletin of the American Geographical Society, by whose permission it is used.

The changes suggested by him, as far as possible, have been made on Coast Survey charts Nos. 8500 and 8651, and will be made on the next edition of No. 8800.

The uncharted harbor on the north side of Cape Douglas, the southwest point of entrance to Cooks Inlet, is included between the rounded low peninsula of Cape Douglas and a narrower cape on the west and north rising about 40 feet from the top of the steep beach. To the south three glaciers are visible, two coming down south of Cape Douglas, and one ending in a stream which discharges into the southern part of the bight. The southernmost glacier is the largest. The shore about Cape Douglas is defended by numerous rocks, and should not be approached too closely. Within the bay, anchorage may be had in 2 to 5 fathoms under the west cape, where the bottom appears to be clear. The south and east parts of the bay are more or less shoal and rocky and should be avoided. In entering, the navigator should keep the western shore aboard. Shelter may be had here in any wind except heavy northerly and northeasterly gales.

Leaving the cape, the northern slope of the mass of mountains behind it is seen to be snow covered, and with three very large snowy glaciers descending to the vicinity of the sea. The easternmost appears to be the largest, and shows an even snowy surface without lateral moraines. Northwest of the group of mountains is a space of comparatively low land crossing the peninsula behind the shoal and dangerous Kamishak Bay. Over these plains many caribou are said to range in summer.

Between Cape Douglas and Augustin Island, and about 6 or 8 miles from the latter, are the Sea Otter Rocks, a low group not definitely placed on the charts. We steamed a straight course NW. ½ W. (p. c.) from the cape in calm, clear weather, which, according to the latest charts, would have carried us directly over the rocks, but in fact carried us about 2 miles west of them. At low water there were two low, flat table rocks, with a smaller pointed one between them, visible at a distance of 2 miles, the eye being 10 feet above the water. At high water they are said to be awash. We brought them in one with a high

bluff, which we supposed to be Point Bede, on the east shore of the inlet, bearing NE. by E. These rocks constitute a serious danger to navigation.

Augustin Island (otherwise Black Fox or Chernobura) is a typical volcanic peak, with low borders of talus. At present, anchorage may be had in 3½ fathoms, sand, about a mile offshore, with the south point bearing SE. by S., the western point NW., and the peak NE. by E. ½ E. The south point is low and sandy, but the boat landing is best here, the beach running off very shoal north of it. The west point is composed of ashes and volcanic stones, forming low, bluff banks, and running off in flats, upon which the bowlders of volcanic rock, sometimes very large, are irregularly distributed. No chart of the island exists. There was formerly an excellent harbor for small craft on the west side, and the inner harbor still exists, but the entrance is now dry at low water. This change was brought about at the time of the last eruption, less than ten years ago. The peak has the regular volcanic form, the rim of the crater being somewhat broken away on the west and north. Steam issues in intermittent puffs from the crater and inner cone, and when these puffs rise vertically and spread out like a mushroom above the peak it is taken as an evidence by the natives of several days of calm weather, during which they do not hesitate to put out far from shore in their frail kyaks to hunt the sea otter. The peak is about 3,000 feet in height.

The upper two-thirds of the peak is largely snow covered; below, much is bare ashes and scattered lava blocks, then more or less herbage with stunted spruce, sparsely scattered, and low, creeping alders. The borders of the island to the south and west are low and hummocky, with many bogs and small pools. The south shore has bluffs of variable height, none very high. The passage west of the island is foul near the island shore, but has a navigable passage rather closer to the mainland shore.

Tuxedni Harbor, sometimes called Snug Harbor, lies between Chisick Island and the mainland. That a snug harbor is to be found here is noted on a sketch chart of the U. S. Hydrographic Office, but that the bay is 5 or 6 miles long, free from dangers, and forming a spacious anchorage, would hardly be supposed from the very imperfect indications given on the best charts. Chisick Island is narrow, and rises over 2,000 feet in height with bluff shores, the water bold-to. There is a small, round, high, rocky islet outside of Chisick, which forms a convenient landmark for vessels feeling their way alongshore in a fog, which sometimes conceals the entrance. The southern end of Chisick is high and narrow, with no reef or rocks off it, as has been erroneously stated. The strata are somewhat inclined to the south near the entrance, but in the main are nearly horizontal, and composed of heavy beds of sandstone and conglomerate of varying hardness, so that the upper part of the island weathers into steps like terraces on a grand

scale, offering a remarkable castellated appearance to the spectator. The scenery here is very fine and peculiar in its features. The splendid volcanic peak of Iliamna rises among the mountains SW. by W. from the harbor at a distance of some 15 miles. Its upper part is set with glaciers, but the conical form and scenic beauty of the peak can only be fully realized from a greater distance. The fairway of the harbor is nearly straight, with high and singularly weathered cliffs rising on either hand. Toward the head it widens a little. Here good holding ground may be had in 18 fathoms. At this point the vessel which carries down the product of the salmon canneries from the inlet is anchored for the summer. The canned salmon is brought to her by small light-draft steam tenders, which can cross the shallow water on the bars of the rivers at Kassiloff and Nenilchik where the salmon are taken.

From Captain Hughes we learned that the spring tide in June was 36 feet; at ordinary times the range is about 24 feet. The northern end of the harbor is protected by reefs and foul ground beyond Chisick Island, where there is a large open bay. There may be a channel out this way, but until it is surveyed it would be imprudent to attempt the passage except with small craft. Into this bay a large river falls, fed by the glaciers of Iliamna and the drainage of the other mountains. The north end of Chisick shows high bluffs rising much above those on the main shore, and above to a magnificent castellated summit of curiously eroded almost horizontal beds of sandstone, limestone, and conglomerate, which can hardly be less than 2,000 feet in elevation. Near the beaches the rocks are worn into caves, arches, and pillars, about which circle innumerable multitudes of sea birds. There is no bar or obstruction at the entrance of the harbor, but the great range of the tides and the narrow form of the harbor produce well-marked rips at certain stages of the tide, which might lead to the supposition that rocks or shoals exist. On the island side the shores are bold-to; on the mainland at the head of the harbor it is shoal for a long distance from the beach. Notwithstanding the absence of protection at the entrance, southerly winds do not blow home into the harbor on account of the high land on either side; but for the same reason wind from the land is often stronger in the harbor than out in the inlet. July 23, 1895, flood tide made shortly after 3 p. m.

All the navigation in the upper part of Cook Inlet is commonly carried on with reference to the tides; a sailing vessel can make no headway against them and it is the custom to anchor during the unfavorable tides, which can be done almost anywhere alongshore. Off the West Foreland there is a small village of Kootena Indians, and here the shore is of bluffs, apparently about 50 feet high, of gravel and sand, wooded above, with some high mountains distant in the interior. It was slack water here about 10 a. m., July 24. Between the two Forelands is a wide bay with shoal water and many scattered bowlders rising out of it

along the shore. The land behind is very low in part, all heavily wooded with spruce, and a river carrying very muddy water comes in here. Near the North Foreland is a series of whitish gravel bluffs of very regular height, with a broad beach and shallow water for a mile off it, with scattered, sometimes very large, squarish rocks of whitish color irregularly distributed over the flats. There are Indian houses in the principal gap in this series of bluffs, but the largest settlement, Tyonek, is near the point of the Foreland where a small gravel flat exists. Here the water off the beach for half a mile is shoal but not foul. Off the Foreland southward, in the middle of the Inlet, most charts show an area inclosed by a dotted line connected continuously with foul ground on the southeast shore of the inlet. This is an error, as there is a clear passage on each side of the central patch, which latter trends with the Inlet and shows at low water large bare sand banks 8 or 10 feet high. East of North Foreland and between it and Point Possession, also in the middle of the Inlet, is a flat or shoal not shown on the charts and which constitutes a serious danger. It is believed to be 5 or 6 miles long and not less than 4 miles wide. Its southern edge is about WSW. (mag.) from Point Possession.

The village of Tyonek is small, without a harbor, and the spot is inaccessible by sea in winter as this part of the Inlet freezes over. The tide is from 25 to 35 feet in range here, with a depth of 3½ fathoms half a mile off the beach. Turnagain Bay extends to the eastward from Point Possession and is the passageway to the placer mines, of which much has been said in the public press.[1]

Northeasterly from Point Possession, on the continent, the land is mostly low, formed by the delta of the Sushitna River. West of the river, at some distance inland, rises a noted landmark, a low but conspicuous peak known as Sushitna Mountain. Eastward from the Sushitna, another, the Knik or Fire River, enters the Inlet north of Point Campbell. West of Point Campbell is a small high island called Fire Island, to which sufficient water for an ordinary schooner may be had at low tide, according to local navigators. Both at Point Campbell and Point Possession the land is low and wooded, but at about 12 miles eastward of the latter the mountains come to the water's edge, with narrow steep-sided ravines and canyons, in which are the streams where gold is washed. The land rises to about 2,000 feet, some of the peaks are higher, and the slopes are rather sparsely wooded. The rise and fall of the tide in Turnagain Bay is remarkable, and the middle of the passage, as well as much of its margin, is occupied by extensive flats, partially dry at low water, with a shallow channel at each side. To enter the bay, and avoid the shoals, keep Point Possession well aboard and steer for the northern edge of the high land on the south side of the bay, keeping a little to the southward of a straight course between the

[1] The U. S. Geological Survey will publish a report by Dr. Becker on the mines of this region.

two; keep the lead constantly going, as the shoals shift to some extent. Allow for a tide of 50 feet in range and select an anchorage in accordance with the circumstances of the case. The northern channel is not navigable eastward of Fire Island, and the island is nearer to Point Campbell and rather more southerly in position than indicated by the existing charts. The shoal in the center of the bay is elongated, trending with the Inlet, and not rounded as on the charts. These shoals are mostly hard sand, with a few scattered bowlders.

The following is a graphic description showing the strength of the tides in this vicinity:

We anchored under the lee of a small, high, conspicuous bluff, the first east of Point Possession, where the miners assured us there was always water enough to float our little tug. It is hardly necessary to repeat that here one can only move with a fair tide. At our anchorage, with the standard compass, we found Point Campbell bearing W. 40° N., the north edge of Point Possession W. 10° N., the SW. edge of Fire Island in one with Point Campbell, Mount Sushitna NW. ½ W., and the bluff point a cable's length to the east. We left North Foreland with the flood tide immediately after it turned at 2 a. m., July 25, and at 8 a. m. found high water at the bluff above mentioned, with 41 feet of water under us. There was a slack of about fifteen minutes. At 9.15 we put out the patent log to test the strength of the ebb, and found it to average 3¼ knots during the first half, though we were out of the strength of the tide. It was slack water at 3.30 p. m., and there was less than 2 feet of water under our bilge, showing a range for this day of 39 feet at this point. We were obliged to await the bore, helpless on the sand, and it did not keep us waiting long, but came in with a rush, in a wave 3 or 4 feet high, which whisked us a mile and a half up the Inlet before we could get out another anchor; and here, with full steam ahead and both anchors down, we had all we could do to keep her from dragging. The log showed a 7-knot current, and the water, after the bore had passed, rose 6 feet in 10 minutes. At extreme spring tides the ebb would leave this anchorage dry and for a mile or two seaward. The force of the current was such as to twist our main anchor, weighing 250 pounds and of good Swedish iron, in two different directions. It was a fit object for a museum when recovered.

Off the highland west of our anchorage is a small high island, called "Haystack" by the miners. It rises out of the flats which dry all around it at low water. Kachemak Bay, on the eastern shore of the Inlet, is interesting on account of the presence of extensive deposits of brown coal, and because it is the finest harbor in the Inlet, never obstructed by ice, and one of the finest on the whole Pacific Coast. It separates the comparatively level plateau of the Kenai Peninsula, west of its axial mountain range, from a spur of that range which comes down to the sea at Point Bede, in which there are several indentations affording anchorage.

These mountains are not very high, but from them descend several attractive glaciers not difficult to reach. The rocks on this side of the bay are mostly crystalline or eruptive, forming a marked contrast to the bluffs of nearly horizontal sandstone and clays with conspicuous coal seams which border the opposite shore. The harbor is protected by a long low spit of gravel, within which is good anchorage close to the shore, but the beach in front of the bluffs makes off shoal for 2 or,

toward the head of the bay, fully 3 miles. The range of tide in the upper bay is 22 feet, but at springs the extreme range is said to be 30 in the upper part of the bay and somewhat less toward the entrance. Excepting a few buildings connected with the work of coal prospectors there is no settlement within the spit. In the lower bay, outside of the harbor, is a snug anchorage, Chesloknu, of the natives, Seldovia or Herring Bay of the Russians. Here are two trading stations, and most of the inhabitants from Port Graham, where the harbor is less convenient, have migrated to Seldovia Village. There is quite a collection of houses and a Greek chapel. No chart has been published of this anchorage, except a small delineation from a Russian sketch which is included in the chart of Kachemak Bay, compiled by the Coast Survey No. 8651. The bluff at the southeast head of the entrance is composed of two small rocky islets united to each other and to the mainland by a low spit, so that the land is not continuously high, as represented on the sketch alluded to. The entrance has rocky bottom clear across, with kelp growing in 5½ fathoms. The northern head is bluff and rocky; a rounded bowlder lies off it, visible at low water. There are also rocks above and below water about the opposite headland. Inside there are 7 and 8 fathoms, sandy bottom, off the village in mid-harbor, with protection from all winds except northwest, and at the head of the harbor complete shelter.

Amalik Harbor lies behind Takhli Island, on the south side of the Alaska Peninsula. We found excellent shelter from all winds and anchorage in 10 fathoms, sand. A long inlet penetrates the land here which has never been surveyed. The rocks are mostly coarse sandstones, pierced by volcanic dikes and contain seams of a superior quality of brown coal.

Coal Bay is a fine sheet of water, of which no charts exist and the indications on the general charts are very inaccurate. The entrance is partially obstructed by an area of foul ground with rocky islets and pinnacles extending to the southwest from the northeastern point of entrance for several miles. Another patch, separated by a clear passage, is nearly in the middle of the entrance. The Russian Hydrographic Chart of 1848 shows these with more accuracy than any of the later maps, but barely indicates the inner shores of the bay. Cape Yaklek forms the southwest headland, and is free from offshore dangers.

There is just within this cape a small spit of heavy shingle with high, rocky bluffs behind it. Here anchorage may be had, in good weather, and the camps of sea otter hunters are often made. There is no settlement in the bay, which is divided into two arms by a high promontory near its head. The western arm terminates in low, flat land, behind which is a large lagoon, dry at low water, into which empties a rather large stream. The land at the head of the eastern arm is higher. Most of the topography about the bay is high and barren, the rocks lying in nearly horizontal heavy beds of sandstone